Journal
of
The Franklin Institute
Devoted to Science and the Mechanic Arts

Vol. 218 AUGUST, 1934 No. 2

THE ATMOSPHERES OF THE STARS.*

BY

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Human knowledge of the atmospheres of the stars reverses the usual order of acquaintance with more familiar things. We knew what they were made of long before we found out what they were like. Knowledge of their composition came suddenly about seventy years ago with the invention of the spectroscope. The work of Huggins and Secchi showed that the stars, like the sun, had continuous spectra crossed by dark lines—indicating that they were opaque, incandescent bodies surrounded by absorbing atmospheres. Some of the more prominent constituents of these atmospheres, such as hydrogen, magnesium, calcium, and iron, were immediately recognized and it became evident that the same kinds of matter were present, and doubtless the same natural laws operative to the utmost distance at which observations were possible. The star's spectrum, then, reflects its chemical composition, or, more precisely, the composition of the atmosphere. One might have expected to find very great variety among them; but from the earliest investigations it became evident that such was not the case. Stellar spectra fall into a very few main types, the first characterized by a relatively small number of lines belonging with few exceptions to the permanent gases, hydrogen, oxygen, nitrogen, and the later

* Presented at the Medal Meeting held Wednesday, May 16, 1934.

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discovered helium. The second great type includes spectra like the sun's, which are very rich in lines, due mainly to the metals, while those of the permanent gases, except hydrogen, are faint or absent. Finally, there are two types distinguished by heavy bands, which under high dispersion are resolved into close packed lines, and have their origin not in free elements but compounds—titanium oxide being prominent in one group and carbon compounds in the other.

The rudimentary analysis of stellar atmospheres therefore raised questions more puzzling than those which it settled. What caused these remarkable differences? Are some stars really made of the light gases and others of metallic vapors? If so, why do we find that the "gaseous" stars are always white and probably extremely hot, while the "metallic" stars are yellow and cooler, and those with banded spectra are red and cooler still? The first rational physical explanation was suggested by Sir Norman Lockyer. Starting with the obvious suggestion that the compounds which absorb the bands can occur only at the lowest stellar temperatures and are decomposed in all the hotter stars, he showed that the lines of the metals themselves, as observed in the laboratory, could be divided into two classes; the ordinary or arc lines which appear in an electric arc and the enhanced lines which are greatly strengthened in a powerful disruptive spark. By a bold generalization he attributed the former to the normal atoms of the metal and the latter to decomposition products of these atoms formed only at very high temperatures. In the laboratory, where the hot vapors must cool again, we cannot obtain the latter without the former, but in certain hottish stars such as Alpha Cygni the enhanced lines of the metals appear without the arc lines, indicating that the process of atomic decomposition is practically complete. For most elements only two stages could be detected, but for silicon four groups of lines, supposed to correspond to successive stages of the dissociation process, were identified in the laboratory and found in hotter and hotter stars. Lockyer's pioneer work thus explained the main characteristics of stellar spectra, including the fact discovered about the same time by Pickering and his collaborators that there existed a continuous sequence of intergrades between the great spectral

classes, and that position in the sequence was very closely correlated with the color of the star's light and hence with its surface temperature. It did not, however, explain why the permanent gases should not show themselves spectroscopically until after the metals had almost completely disappeared.

Later investigations, such as those of King at Mount Wilson, showed that among the arc lines of such a metal as calcium, some are absorbed by the vapor at low temperatures while others require higher temperatures to bring them out. Lines of the former group are characteristically strengthened in the sun-spots, and Hale and his colleagues thus first established beyond question that the spots were cooler than the rest of the disk.

All this work was empirical and qualitative. A quantitative physical theory was made possible by the development of modern spectroscopy by Bohr and a multitude of followers and by the astrophysical application of the theory of ionization by Saha in 1920. We now know that the arc lines of any element are produced by the neutral atoms and the enhanced lines by ionized atoms which have lost an electron apiece (and are therefore truly decomposition products in Lockyer's sense). Atoms which have lost two or more electrons usually have their lines so far in the ultra-violet that we cannot observe them through the earth's atmosphere. In a few cases we can, and Lockyer's four groups of silicon lines are known to represent four successive stages of the ionization process. A neutral atom does not absorb all the lines of its complicated spectrum at once. Some, the ultimate lines, are produced by the atom in its normal state; others only by atoms which, though still retaining all their electrons, have been excited or loaded with energy. At low temperatures these excited atoms are very few. With rising temperature their proportional number increases and the corresponding lines strengthen. The ultimate lines of most of the metals are in the part of the spectrum which is accessible to observation in the stars. Those of the permanent gases are not, and we must depend on lines absorbed by highly excited atoms which are present in negligible amounts except at very high temperatures.

The general character of the spectral sequence is now

fully intelligible. Even at the lowest stellar temperatures most compounds are dissociated into their elements; but a few hardy ones are left in sufficient amount to produce the well-known bands. With rising temperature these disappear and the metallic arc lines dominate the spectra. Enhanced lines of the ionized metals strengthen in the hotter stars while the arc lines weaken and finally fade out. The hydrogen lines, which are absorbed only by highly excited neutral atoms, strengthen steadily until the hydrogen itself begins to be ionized, and then fade again, while the still more difficultly excited lines of helium then appear. In the hottest stars, the metallic atoms are two or three times ionized, and put out of commission as far as visible lines are concerned, while even the more refractory atoms of the permanent gases are ionized repeatedly but still have a few lines to betray their presence. The great differences between the various types of stellar spectra thus depend not primarily upon actual differences in composition but upon the way in which the atoms are ionized and excited at different temperatures. We might imagine an artificial star composed of a solid incandescent body surrounded with an atmosphere fixed in composition and in extent. As the temperature of the core was slowly raised its spectrum would pass through a series of stages resembling the actual sequence of stellar spectra almost to perfection. Differences in actual composition, however, have to be invoked among the red stars, as the late R. H. Curtiss suggested. The metallic oxides would form in an atmosphere containing an excess of oxygen, while if carbon were in excess the oxides would be decomposed and carbon compounds would take their place.

Ionization is favored by low pressure as well as by high temperature. If we know the temperature at which a given line has its maximum intensity (i.e. at which the number of atoms in a given state of ionization and excitation is the greatest) it is possible to work backward and find the atmospheric pressure or at least that part of it due to free electrons, as was first done by Fowler and Milne. The calculated values are exceedingly small, 1/10,000 of ordinary atmospheric pressure or even less. Stellar atmospheres must therefore be exceedingly thin—a conclusion confirmed by a great mass of

other evidence, which indicates that the whole amount of gas above the sun's visible surface is equivalent to a layer of air only a few feet thick.

The reason why we cannot see deeper into the stars was first realized by J. Q. Stewart. Under familiar conditions gases are transparent in a thickness of miles, but an ionized gas containing free electrons and charged atoms, is a very different affair, and by the general laws of radiation must necessarily be foggy or hazy. The effect depends on the collisions between the charged particles, and increases with the density of the gas. Its amount may be approximately, though not exactly, calculated from general atomic properties and it is found that it should actually become important at the low pressures already mentioned. A star's "atmosphere" is, therefore, a remarkably ill-defined affair,—bounded at the top by a vacuum and at the bottom by a fog,—thinning off gradually on one side into empty space and slowly becoming more and more hazy on the other. The upper layers must be decidedly, though not very greatly, cooler than the lower, while the pressure diminishes steadily from a finite value near the base to nothing at all at the top. An exact calculation of the integrated absorption produced by all the layers of this complex atmosphere would be very difficult. Fortunately Professor Milne has shown that it is not necessary. We may substitute a fictitious atmosphere of constant temperature, constant pressure, and definite thickness, and obtain an extraordinarily good approximation to the actual line absorption, provided we choose these constants in the proper way; the temperature, for example, being that derived substantially from the color of the star's light. The effective depth of the atmosphere depends mainly on the force of gravity at the star's surface. When this is small, a layer containing the same amount of material per square mile will be under smaller pressure, of lower density, and more transparent, so that the effective thickness will be greater. This increase in the "amount of material above the photosphere," combined with the increased ionization due to lower pressure, accounts for the differences in the spectra of giant and dwarf stars which are so important in the spectroscopic determination of absolute magnitude and parallax. The effective thick-

ness of the atmosphere depends, however, also, and very importantly, upon its composition. Suppose, for example, a star with an atmosphere composed exclusively of hydrogen. Hydrogen is hard to ionize, and at a temperature like the sun's very few free electrons and ions will be present. The gas would be highly transparent and the depth down to the fog very great. Although the fraction of hydrogen atoms which were highly enough excited to absorb the observable lines is very small, the total number in so great a thickness would be large and our hypothetical star would show strong hydrogen lines. Now add to the atmosphere one part in a thousand of sodium. This will be almost completely ionized and will contribute a number of free electrons and of ions greatly exceeding that derived from the scanty ionization of the more abundant hydrogen. The opacity of the atmosphere will be enormously increased, and its effective thickness greatly diminished, thereby reducing the hydrogen lines to a small fraction of their previous strength. In general, the strength of the lines of a given element and the temperature at which they attain a maximum may be strongly influenced by the presence of other elements—sometimes even in small quantity. Calculations of what ought to happen in a real stellar atmosphere are therefore none too simple, and we should be quite at a loss if there were not other means of estimating the composition of the atmosphere. From a study of the intensity of lines of various elements in the solar spectrum, Dr. Adams, Miss Moore, and I have derived a calibration which gives approximately the number of atoms at work in absorbing any particular line. From this it is possible, with various precautions, to estimate the total number of atoms of the different elements in the atmosphere. The relative abundance of metallic elements can be found quite reliably. There is conclusive evidence that hydrogen is very much more abundant than all the metals together, but a precise estimate is not practicable. One may be obtained, however, by using the principles just discussed. To remove one electron from an iron atom is much easier than to take it from hydrogen, but to remove the second is decidedly more difficult. We would therefore expect in a sequence of stars of rising temperature, that the arc lines of iron

would weaken early, but that the enhanced lines of iron would hold out to considerably higher temperatures than those of neutral hydrogen. As a matter of fact, however, they weaken when the hydrogen lines are still strong, and almost disappear before the latter are greatly weakened. This is another instance of the way in which one element influences the behavior of the lines of another. Consider an atmosphere consisting mainly of hydrogen with a small amount of iron. At low temperature, practically all the electrons will come from the iron, the atmosphere will be transparent, and its depth will be great. If the hydrogen could not be ionized there would be very little change in the number of free electrons and the depth of the atmosphere between the temperature at which the first ionization of the iron was substantially completed and the much higher temperature at which second ionization began to be important. Throughout this interval the enhanced lines of iron would remain strong; but near the middle of the interval the hydrogen becomes ionized and, since its atoms are very numerous, produces a great increase in the opacity and a corresponding diminution in the thickness of the atmosphere and the strength of the iron lines. These lines will then begin to weaken as soon as the hydrogen liberates more electrons than the iron, while only a small fraction of it is ionized and while the hydrogen lines are at full strength. The observed effect is very pronounced and indicates that the hydrogen must be a thousand times as abundant, atom for atom, as the iron (and, indeed, all the other metals, ignored above for simplicity of statement).

A fair approximation to the opacity of a real stellar atmosphere can be obtained from a simplified "model" composed of one thousand parts of hydrogen and one of metals, three-fourths of the atoms of the latter being iron, three-fourths of the rest sodium, and the remainder potassium. The other metals of difficult ionization, such as magnesium and silicon, are lumped with the iron; and those of easier ionization, like calcium, with the sodium. Adjusting one constant to fit the known extent of the sun's atmosphere we then obtain formulae by which the extent of atmosphere and the electron pressure (which determines the ionization) can be computed

for a star of the same composition but of any other values of the surface temperature and surface gravity. The diameters and masses are known for a sufficient number of stars to give us these necessary data. For the stars of the main

FIG. 1.

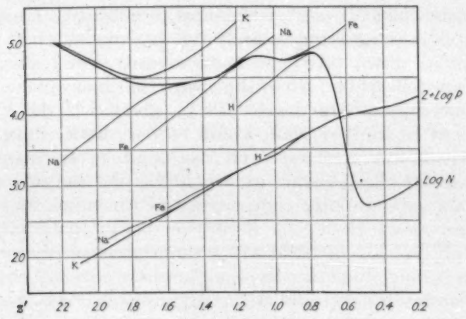
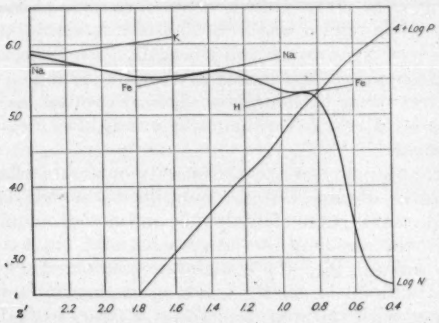


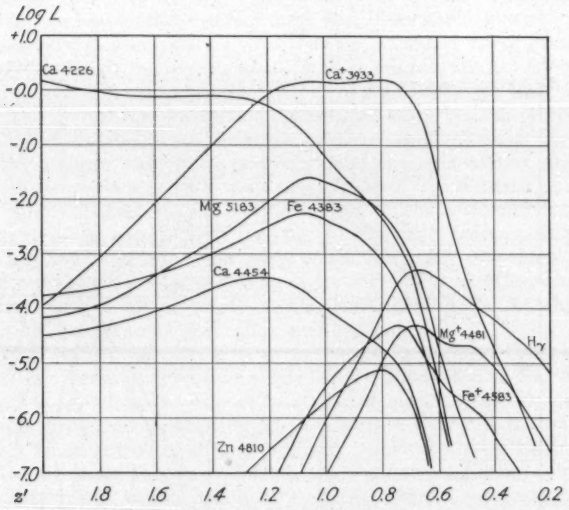
FIG. 2.



sequence, ranging from the hot white stars in Orion through Sirius and the sun to the faint red dwarfs, the surface gravity increases slowly for the cooler stars. Figure 1 shows what

should happen in their atmospheres. The vertical coördinate represents the extent of the atmosphere on a logarithmic scale, while the horizontal coördinate is $z' = 5040/T$, T being the star's temperature. (To use the reciprocal of the temperature makes the diagram considerably simpler.) The line marked sodium, for example, shows the extent of atmosphere to be

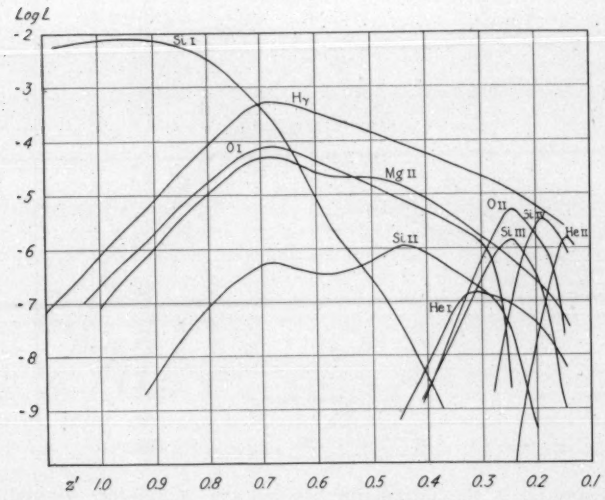
FIG. 3.



expected if the potassium was always completely ionized, the sodium undergoing ionization and nothing happening to the remaining atoms. At low temperatures, $z' = 2$, the line rises toward the right since at higher temperatures the electron fog becomes less dense and we can see deeper. Between 1.8 and 1.2 the sodium becomes ionized, increasing the fog, and the rise drops off, to be resumed again when the sodium is completely ionized. The next curve, marked iron, shows the effect of ionization of the iron, which adds additional opacity to the atmosphere and prevents the increase in extent

which would otherwise occur. Finally the curve marked hydrogen shows how the ionization of the abundant hydrogen greatly increases the opacity and cuts down the depth of the atmosphere. The heavy curve marked log N indicates the combined effect of all these processes.[1] The other curve marked "$2 + \log P$" shows how the pressure due to the free electrons steadily increases as more and more material is ionized. Figure 2 shows a similar curve for giant stars, in

FIG. 4.



which the force of gravity and the pressure is very small among the larger and redder ones. The most important character of the resultant curve, in both these figures, is that it runs nearly horizontal, with minor oscillations, for values of z' greater than 0.8, i.e. for temperatures below 6300°. In other words, the increase in atmospheric opacity due to the

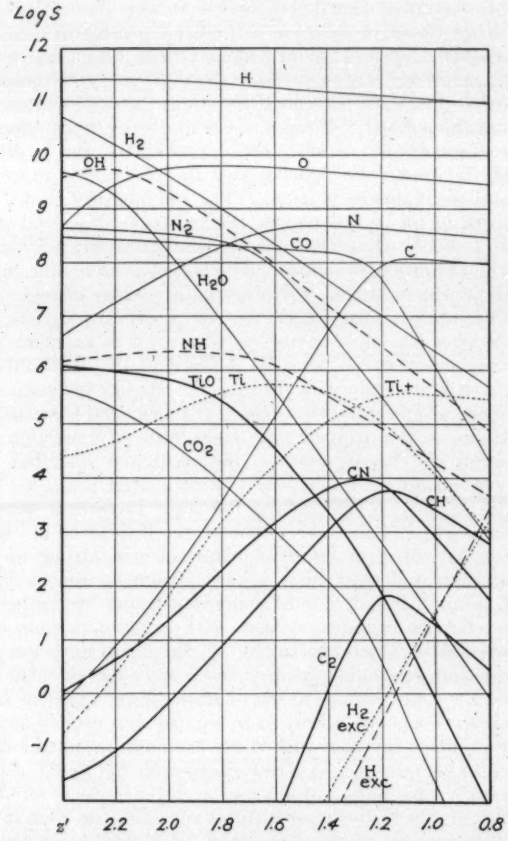
[1] For details see Mt. Wilson Contribution, No. 477: *Astrophysical Journal*, **78**, 284, 1933.

ionization of more and more of the atoms in the atmosphere roughly balances the decrease due to the diminished fog-producing power of each ion at higher temperatures, so that the effective depth of the atmosphere does not change much. This explains why the elementary assumption of an atmosphere of fixed extent gave such good results in the earlier investigations of the subject. From $z' = 0.8$ to 0.5, i.e. from temperatures of 6000° to 10,000°, the ionization of the hydrogen greatly increases the opacity and the observable extent of atmosphere is much curtailed. The rudimentary theory will not work at all in this region, but it is tolerably good again above 10,000°, when the hydrogen is practically all ionized and the liberation of additional electrons from helium or the metals produces but an insignificant percentage change.

With these values for the extent of the atmosphere and the electron pressure we may now proceed to calculate how the number of atoms actually engaged in the absorption of any given line should vary for stars of different temperatures. We must bear in mind that only a fraction, and sometimes a small one, of the atoms in the right state of ionization and excitation will be at work on the particular line, but this fraction can often be tolerably well estimated.

The results of calculations for some important lines in the cooler stars of the main sequence are illustrated in Fig. 3. λ4226 is an ultimate line of neutral calcium, strong at low temperature and weakening as the calcium becomes ionized. λ3933 is an ultimate line of ionized calcium, strengthening as the element becomes ionized, with a flat maximum over the interval in which practically all the atoms have lost one electron and weakening again as more and more of them lose a second. Lines such as λ5183 of magnesium, λ4383 of iron, and λ4810 of zinc are absorbed by neutral but excited atoms, whose numbers increase with rising temperature until ionization cuts them down. λ4481 of magnesium and λ4583 of iron are absorbed by ionized atoms and would increase in strength to considerably higher temperatures than they do were it not for the fogging up of the atmosphere by ionized hydrogen, as already described. Figure '4' shows the behavior of certain lines prominent in the hotter stars. Those marked *Si* I, *Si* II, *Si* III, *Si* IV, represent the four groups of silicon lines recognized long ago by Lockyer.

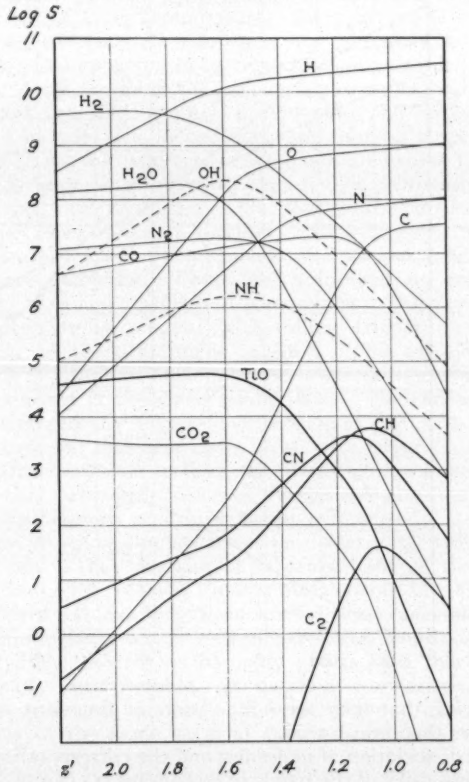
FIG. 5.



The spectral classes and hence the temperatures at which the various lines actually reach their maximum intensity were determined ten years ago by the careful observations of

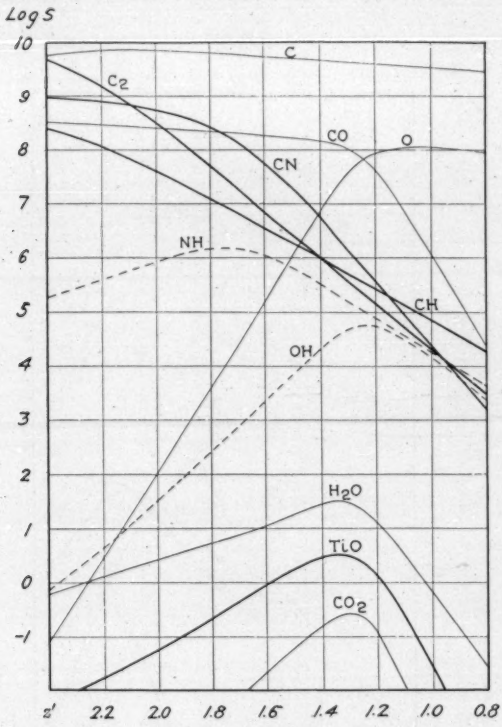
Miss Payne. The agreement with the results of the present theory is usually quite within the errors of the observations. It may fairly be claimed, therefore, that the theoretical study of stellar atmospheres has now gone far enough to give a good general explanation of the observed sequence of spectra. A

FIG. 6.



great many more problems remain to be solved. For example, practically all existing theories indicate that the dark lines should be quite black at the middle and all observations agree

FIG. 7.



in showing that they are not. There is abundant room for extensive theoretical work.

The dissociation of molecules and the corresponding variation of intensity of the bands in stellar spectra can be handled

in very much the same fashion. We need to know how much energy is required to dissociate a molecule into its elements (just as in the previous case we required to know how much was necessary to ionize it). These data are available, though not very accurate, for most of the important molecules, and the necessary calculations can be made. Figure [5][2] shows what should happen in giant stars of composition similar to the sun, but of lower temperature. Here oxygen is in great excess over carbon. At a temperature of 6300° ($z' = 0.8$ in the figure), the oxygen and carbon atoms are almost all free. At about 4200°, $z' = 1.2$, the carbon begins to be oxidized in large quantities, forming carbon monoxide, and below 3600° ($z' = 1.4$), most of it is locked up in the compound, as shown by the *CO* curve. Oxygen is so much in excess that its amount is very little affected, but at low temperatures it combines with the hydrogen at first to form the half-molecule *OH*, which then takes up another hydrogen atom to form H_2O or water vapor. The amounts for various other compounds are exhibited. Those which interest us most are titanium oxide and the carbon compounds. The former increases steadily in amount with falling temperature until practically all the titanium is oxidized. This explains why the bands of titanium oxide increase in strength and become very prominent in the cooler giant stars. The carbon compounds *CH* and *CN* (cyanogen) increase at first with falling temperature but diminish again as an ever larger proportion of the carbon is taken to form the more tightly bound molecule of *CO*. This behavior was recognized observationally some years before it was theoretically explained.

Figure [6] shows similar curves for dwarf stars of the sun's composition. They are similar in general shape; the curve for titanium oxide reaches its maximum sooner but does not rise so high. It has long been known observationally that the titanium oxide bands were never found so strong, even in the reddest dwarfs, as in many giants, and this is now theoretically interpretable. A detailed comparison shows that the cyanogen bands should be stronger in giants than in dwarfs of the same spectral type as ordinarily defined.

[2] For details see Mt. Wilson Contribution, No. 490: *Astrophysical Journal*, 79, 317, 1934.

This again has been known observationally for a number of years.

Finally, Figure [7] shows what is to be expected in stars containing much more carbon than oxygen. Here the formation of carbon monoxide uses up the oxygen instead of the carbon and prevents the quantity of titanium oxide from ever becoming large enough to produce perceptible bands. On the other hand, the carbon compounds are present in very large amounts at the lower temperatures, and should produce bands heavier than titanium oxide ever does. Such bands are actually found in the stars of classes R and N and the correctness of Curtiss' interpretation of the differences between these spectral types is fully confirmed. Among these red stars we have to deal with the true astronomical chemistry in which the laws of dissociation and mass action are beautifully exhibited. Only a first attack has been made in a field where extensive work both of observation and theory is still required.

PRINCETON UNIVERSITY OBSERVATORY,
May 12, 1934.

MECHANICAL PROPERTIES OF MONOMOLECULAR FILMS.*

BY

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A thin film consisting of a single layer of foreign atoms on the surface of a solid may profoundly modify the chemical and physical properties of the surface. For example, a tungsten filament heated to 1500° K. rapidly decomposes various gases such as methane, or ammonia, but if enough oxygen is at first added to form a single layer of atoms covering the surface, this power of the hot tungsten layer to decompose these gases has been destroyed. The oxygen thus acts as a catalytic poison.

A single layer of thorium atoms on the surface of a tungsten filament may increase the electron emission at a suitable temperature 10^5-fold. With a layer of cæsium atoms this multiplying factor is as great as 10^{22}.

Although these chemical and physical effects of monatomic adsorbed films on solid surfaces are so striking, it is not ordinarily possible to observe directly any change in the mechanical properties of these solid surfaces. However, monomolecular films of many different organic substances are easily produced on water. These films are most easily observed and studied by their mechanical effects.

The most obvious of these effects is the lowering of the surface tension of the water caused by the presence of adsorbed substances. We are all familiar with the changes in the mechanical properties of water produced by the addition of soap. This effect is strikingly seen if we dip a finger of one hand into a glass of pure water and a finger of the other hand into a glass of soapy water. When withdrawing the fingers, drops of water fall from them. The drops of pure water are, however, several times larger than those of the

* Presented at the Medal meeting held Wednesday, May 16, 1934.

soapy water. The ease with which soap bubbles can be formed in the soapy water illustrates another change in the mechanical properties of the water.

Willard Gibbs showed from the laws of thermodynamics that a lowering of the surface tension of a liquid by a dissolved substance is always caused by a crowding of the molecules of this substance into a film on the surface.

Studies of many cases of adsorption of gases on solid surfaces have shown that in most typical cases of adsorption there is a strong tendency for the film to be one atom thick. This is the result of the short ranges of the forces that act between atoms and molecules. If we consider, for example, the equilibrium between a gas and a solid surface, we may picture the mechanism of adsorption as follows: The molecules of the gas that strike the surface of a solid usually condense on it instead of rebounding from it elastically. The condensed molecules can evaporate from the surface if the temperature is sufficiently high. The rate of evaporation depends not only on the temperature, but also on the forces of attraction between the adsorbed molecule and the underlying solid. Thus the molecules have a certain average life on the surface and the amount of the adsorbed substance at a given temperature depends upon this life.

If the temperature is low enough so that the molecules that are awaiting their turn to evaporate practically cover the surface, additional molecules which strike the surface from the gas are not able immediately to find vacant places in the first layer which they can occupy. They therefore condense into a second layer. An example of this kind which we have studied in great detail is that of cæsium vapor in contact with a tungsten filament.[1] As the pressure of the cæsium vapor is raised, or temperature of the filament is lowered, the number of cæsium atoms adsorbed on the surface tends to reach a constant limiting value corresponding to a single layer of atoms. When the surface is nearly completely covered so that atoms arriving from the vapor are forced to remain in a second layer, these atoms, being no longer in contact with tungsten, are held by forces so weak that they evaporate at room temperature about 10^{36} times faster than single atoms

[1] J. B. Taylor and I. Langmuir, *Phys. Rev.*, **44**, 423 (1933).

which are adsorbed on a pure tungsten surface, and therefore the number of atoms in the second layer is negligible until the vapor is nearly saturated. This huge difference in the forces that hold atoms in the first and in the second layers is evidence of the very short range of the forces.

Thus when a surface is covered with a single layer of atoms its properties are in general completely modified. It is not always necessary, as in the case of cæsium on tungsten, that the rate of evaporation from the second layer shall be greater than that from the first. A good example in which the atoms evaporate much more slowly from the second layer than from the first has been observed in the case of mercury atoms which are allowed to strike upon a cool glass surface. Mercury atoms have a much greater affinity for one another than they have for glass. The mercury atoms in the second layer, being in contact with other mercury atoms, therefore evaporate much more slowly than do single atoms in the first layer. Under these conditions the temperature of the glass has to be lowered far below the temperature corresponding to saturated vapor before any appreciable number of atoms are present in the first layer. If the pressure is then raised sufficiently, these atoms in the first layer begin to form clusters which readily become covered by a second layer since the second layer is relatively so stable; the third, fourth, and subsequent layers thus begin to form on these nuclei even before the first layer is complete. This leads to the formation of droplets of mercury on the glass surface, or, at low temperatures, small detached crystals appear. There is nothing abnormal about this kind of condensation on solid surfaces. It is typical of the cases where the forces between adsorbed atoms are greater than those between these atoms and the underlying surface. These cases, however, do not give us the typical phenomenon of adsorption. It is just because the formation of uniform layers of adsorbed molecules requires that the forces between the adsorbed molecules shall be less than those exerted by the underlying surface that adsorbed films are only rarely more than one molecule in thickness.

Among organic chemical compounds the straight-chain hydrocarbons are of particular interest because of the simplicity of their properties. The molecules of these substances

consist of long chains in which each link consists of CH_2 the ends of the chain being formed of CH_3 groups.

When a drop of a so-called pure mineral oil, or a pure saturated hydrocarbon, is placed upon water, it floats on the water as a circular lens having a definite circular boundary where the oil, water, and air meet. At this junction, the three surfaces (the air-water, the air-oil, and the oil-water interfaces) form definite angles with one another, so-called "contact angles" which depend solely on the three surface tensions (γ_1, γ_2, and γ_{12}).

If we imagine an oil lens of this sort to be constrained by some force to spead out to a very thin film over the surface of the water, we can readily analyze the conditions that must be fulfilled in order than an oil can form such lenses on the surface of water. Outside of the lens there is the surface tension, γ_1, of the pure water. Within the boundary of the lens there are two surfaces—the oil-air interface and the oil-water interface which have the surface tensions γ_2 and γ_{12}, respectively. In order that the thin lens may be stable, it is evidently necessary that γ_1 shall be equal to $\gamma_2 + \gamma_{12}$. If these forces are not equal, the lens will either spread out indefinitely or will contract into a lens of such thickness that gravitational forces prevent further contraction. We may thus define a quantity F_s which has been termed by Harkins the spreading coefficient;

$$F_s = \gamma_1 - \gamma_2 - \gamma_{12}. \qquad (1)$$

Evidently for those substances which do not spread on water, F_s has a negative value. Whenever F_s is positive, the subtance spreads on the water.

A typical hydrocarbon is tetradecane, $C_{14}H_{30}$, whose molecules consist of long chains. This substance does not spread on water and measurements show in fact that $F_s = -6.2$ dynes/cm.

There are large numbers of oils and fats, especially those of animal and vegetable origin, which, when placed on water, spread out to form extremely thin films of the order of 10^{-7} cm. thick. It is found that the general characteristic of all such substances that spread is that they contain in their molecules certain groups of atoms which have an affinity for water and are therefore called hydrophilic. The most com-

mon of these groups is the $-OH$ group or the $-COOH$ group. If such a group is substituted for one of the hydrogen atoms in each of the molecules of a lower hydrocarbon, the effect is to increase the solubility of the substance in water. For example, butyric acid is quite soluble in water, but propane is only slightly soluble.

The substances that spread as thin films upon water are thus substances whose molecules possess a composite surface, most of the molecule having very little affinity for water, thus being hydrophobic, while another portion of the molecular surface is hydrophilic. By spreading on the surface of the water, the molecules can thus arrange themselves so that the hydrophilic portion of each molecule comes into contact with water without bringing the hydrophobic portion in contact with the water. In most of the common fatty acids, the COOH group is at the end of the long chain. Thus when the molecules spread over the surface of the water, they become approximately vertically arranged on the water with the heads (hydrophilic groups) in the water and their tails (hydrophobic groups) packed side by side above the layer that contains the heads.

Because of the affinity of the hydrocarbon parts of the molecules for each other, the molecules spread out on the surface of the water only far enough for their heads to come in contact with the water. The surface tension of the water, therefore, is not decreased unless enough fatty acid is added to completely cover the surface with a monomoleeular film. By measuring the volume of oil required to form a monomolecular film covering a given area, the thickness of the film can be calculated. This thickness is evidently the length of the molecules since these are arranged approximately vertically in the film.

By placing a known number of molecules on the surface and measuring the area to which the film spreads before the surface tension becomes that of pure water, the area per molecule can be measured. This gives the cross-section of the molecule. These experiments enable us to find the shapes of the molecules.

It is very useful to look upon the lowering of the surface tension of water produced by the presence of an oil film as

being the result of a spreading force F produced by the action of the adsorbed molecules on one another. This force is defined as

$$F = \gamma_0 - \gamma, \tag{2}$$

where γ_0 is the surface tension of pure water and γ is the surface tension of the water after the surface tension has been lowered by the presence of the film.

The spreading force F which characterizes any given adsorbed film is entirely analogous to the pressure p which a gas or liquid exerts on the walls of a container. The pressure of a gas or liquid depends on the concentration and on the temperature. The relation between these quantities is usually referred to as the equation of state. Thus an ideal gas is characterized by the equation

$$pv = kT, \tag{3}$$

where v is the volume per molecule and k is the Boltzmann constant 1.37×10^{16} erg deg.$^{-1}$. It is usually more convenient to express this equation in the term of n, the number of molecules per unit volume. The equation then takes the form

$$p = nkT. \tag{4}$$

The analogy between p and F becomes very striking if we measure F not by measurements of surface tension but directly by a surface balance. In this apparatus the surface of water in a long rectangular tray is divided by a floating barrier which is attached to the pointer of a balance so arranged that a horizontal force exerted on the barrier can be measured. When there is clean water on both sides of the barrier the balance reads zero. A definite amount of an oil is placed on the water on one side of the barrier and this is confined to a given area by a second barrier parallel to the first. By moving the second barrier the film can be compressed so that it exerts a force on the balance and at the same time the area covered by the film can be measured. By progressively changing the area, by moving the second barrier, the force F may be measured as a function of a. Any equation which expresses F as a function of a and T is thus an equation of state for the 2-di-

mensional adsorbed film. If the adsorbed molecules do not exert any forces on one another, but exert forces only on the barriers which prevent the thermal agitation of the molecules from causing indefinite spreading, then they should behave as an ideal 2-dimensional gas. Thermodynamical reasoning then indicates that the equation of state should be

$$Fa = kT \text{ or } F = \sigma kT, \tag{5}$$

where a is the area per molecule and σ is the number of molecules per unit area in the adsorbed film. Comparison of these equations with Eqs. (3) and (4) shows the complete analogy between these 2-dimensional gases and a typical 3-dimensional gas. Some experiments of N. K. Adam [2] have shown, in fact, that there are some substances which form films on water that behave like 2-dimensional ideal gases.

The typical films produced on water by fatty acids and other oily substances have properties which indicate that they are 2-dimensional liquids and solids rather than gases, for they do not spread indefinitely, but the value of F becomes zero when the surface concentration σ falls to a definite value. The mechanical properties of these films indicate clearly that they can exist in either the liquid or the solid state. For example, films of fatty acids on water which is slightly alkaline are definitely solid as is seen by the fact that when they are under even a very slight external pressure they can withstand considerable shearing stresses. On the other hand, a monomolecular film of cetyl alcohol, $C_{16}H_{33}OH$, on water behaves like a 2-dimensional liquid; for even under high surface compression it can be made to circulate freely by blowing on it gently.

There is a very interesting type of monomolecular oil film on water which seems to have no analogue in the 3-dimensional world. I refer to the expanded films which are observed when saturated fatty acids are placed on slightly acidulated water (N/100 HCl). N. K. Adam has obtained the F–a diagrams for many of these expanded films at a series of temperatures. The following theory seems to offer an adequate explanation of the characteristics of these films.[3]

[2] N. K. Adam, Physics and Chemistry of Surfaces, Clarendon Press (1930).
[3] I. Langmuir, *J. Chem. Physics*, 1, 756 (1933).

We may assume that in a condensed film the hydrocarbon chains are packed side by side very much as they are in a crystal in a solid fatty acid, and the heads of the molecules are at the water surface with a spacing which is determined principally by the packing of the tails.

In the expanded films, on the other hand, the hydrocarbon tails form essentially a thin layer of a hydrocarbon liquid whose component molecules are free to move relative to one another just as in any ordinary liquid, except that one end of each molecule is constrained to stay in contact with the water because of the head or hydrophil group which is attached to it. This constraint however does not prevent the film from acting as a "duplex film" consisting of an upper surface, which is essentially a surface between hydrocarbon and air, and a lower surface, which is an interface between hydrocarbon and water. In this lower interface the heads or hydrophil groups are free to move as molecules of a 2-dimensional gas.

If it were not for the heads the whole duplex film would possess a negative spreading coefficient F_0, which, for the case of myristic acid films on N/100 hydrochloric acid, is $-$ 11.2 dynes cm.$^{-1}$. It is only the spreading force due to the heads which makes it possible for this film to spread out over the surface of the water. Thus unless this spreading force exceeds $+11.2$, no observed spreading force can be measured by the balance method. On this basis we may assume that the spreading force F_{12}, due to the presence of the heads in the interface, is given by the equation of state,

$$F_{12}(a - a_0) = kT, \tag{6}$$

which is the equation of state of an ideal gas with a correction a_0 for the area occupied by the molecules when highly compressed, this expression being analogous to that involved in Van der Waals' equation. However, the experiments do not measure F_{12} directly, but they measure the algebraic sum $F_{12} + F_0$. It thus follows that the equation of state for the duplex film should be

$$(F - F_0)(a - a_0) = kT, \tag{7}$$

where F is the force directly measurable by the balance.

This equation has been found, in fact, to agree well with practically all observed cases of expanded films.

The expanded film is thus a peculiar case in which the film consists of a lower surface in which the heads behave as a gas film within a duplex film which is behaving essentially like a thin, confined oil lens.

Another interesting characteristic of the F_a curves of expanded films is that they often show a kink where the curve departs abruptly from that which corresponds to Eq. (7). It has been shown that this is due to a kind of incipient crystallization by which groups of molecules in the expanded film coalesce to form micelles in which the hydrocarbon chain has much the same relation as in the condensed film. This kind of a transition also seems to have no analogue in the 3-dimensional world. The micelles possess some of the properties of solids and exert a kind of 2-dimensional vapor pressure and yet they act as gas molecules and thereby contribute to the 2-dimensional pressure.

Within the last year with Dr. Katharine B. Blodgett I have been studying the equation of state of adsorbed molecules at the interface between oil and water to see whether the properties of this interface are consistent with those that were postulated to explain expanded films. This work is still in progress but we have already obtained complete confirmation of Eq. (6) and have also found at these interfaces the same kink which we believe characterizes the formation of micelles in the expanded films. I shall tell you more of some of these results a little later.

The substances which spread on water to form insoluble monomolecular films can usually be made to form monomolecular films on various solid bodies. Because of the rigidity of a solid it is not possible to observe the surface tension of a solid surface and therefore the spreading force F which corresponds to the adsorbed film on a solid cannot be measured directly. If the adsorbed film on the solid surface is in thermal equilibrium with the vapor in the surrounding space, or with a solution of the substance in a liquid, Gibbs' equation,

$$\frac{dF}{d \ln p} = \sigma kT, \qquad (8)$$

can be used to calculate F from the observed vapor pressures (or osmotic pressures), when σ, the number of molecules adsorbed on the surface, can also be determined. In the case of cæsium films on tungsten it has been possible to measure accurately σ as a function of T and p, the pressure of the cæsium vapor. The equation of state thus obtained can be correlated with the forces acting between the adsorbed cæsium atoms by the Clausius virial equation. In this way it has been possible to show that the adsorbed atoms act as dipoles and the dipole moment M can be determined. From this dipole moment it is also possible to calculate the electron emission of the tungsten filament as a function of temperature and of σ. Thermodynamical reasoning also makes it possible to calculate the rate of evaporation of positive cæsium ions from the dipole moment. The good agreement between these calculated values and the measured values of the electron emission and the ion emission justifies the concept of the spreading force F for adsorbed films on solids.[1] The same equations that were derived from the study of films of cæsium on tungsten have also been found to apply equally well to the determination of the relationship between the electron emission between thoriated tungsten filaments and the rate of evaporation of thorium from these filaments.[4]

There are many phenomena which demonstrate that, at least at high temperatures, adsorbed atoms on metallic surfaces can migrate or diffuse over the surface. For example, if thorium atoms are evaporated onto one side of the tungsten filament and the filament is maintained a few minutes at 1700° K., it is found that the thorium becomes uniformly distributed over the surface.

Oil Films on Solids.—There are several methods by which monomolecular oil films may be applied to glass surfaces. The glass should at first be cleaned by heating it in a mixture of sulphuric acid and chromic acid and then washed in grease-free water and dried. If such a glass surface is brought into contact with the vapors of a slightly volatile fatty acid, a monomolecular film of this acid condenses on the glass. Such films may also be formed by dipping the glass into a solution of a non-volatile acid in benzol, and then removing any ex-

[4] I. Langmuir, JOUR. FRANK. INST., 217, 543 (1934).

cess fatty acid by several rinsings in benzol. If some crystals of cetyl alcohol are placed on glass and the glass heated until the substance melts, the drops of liquid can be moved over the surface of the glass without wetting the glass. There is, however, a monomolecular film remaining on the glass after this procedure.

Some particularly interesting results are obtained by transferring a monomolecular film from a water surface to a glass surface.[5] Under certain conditions it is possible in this way to apply several layers of molecules, one after the other, to a glass surface. For this purpose a stearic acid film may be produced on slightly alkaline water * and by a movable barrier and another one attached to a balance, a surface pressure of about 10 dynes per cm. is applied. A clean glass slide is then dipped below the surface of the water. Experiments prove that in passing this way through the surface the glass does not take up a film of stearic acid, but if the slide is slowly withdrawn while the barrier is continually moved forward so as to maintain a constant pressure of 10 dynes per cm., then the glass comes out perfectly dry. The area through which the barrier has to be moved is found to be equal to the total area of the glass slide, so that the monomolecular film has been transferred from the water to the glass without any change in the relative spacings of the molecules on the surface.

If now the glass slide is dipped a second time into the water holding the surface pressure constant, it is found that a second layer of molecules is transferred to the glass. On withdrawing the glass, a third layer is formed.

The odd numbered layers of molecules are oriented with the hydrophil groups towards the glass, while the even numbered layers are oriented in the opposite direction.

There are many ways in which the presence of such monomolecular films on glass can be detected, and some of the

[5] K. B. Blodgett, *Jour. Amer. Chem. Soc.*, **56**, 495 (1934).

* In most of these experiments water from the city mains was used, but in some cases the distilled water which is piped through the Laboratory was tried. Later experiments suggest that traces of calcium in the alkaline water are perhaps necessary in the formation of these multimolecular layers. These multimolecular layers may be layers of sodium or calcium stearate, although I shall refer to them as stearic acid films.

properties of these films may be accurately measured. In general if a drop of water is placed on a glass surface which is covered with a monomolecular oil film, it is seen that the water does not wet the surface; that is, it forms drops on the surface which show a contact angle against the surface. For example, if a drop of water is placed on a block of solid paraffin, it is seen that the drop assumes a nearly spherical form. The contact angle of the paraffin being about 110°, the water actually overhangs the circle representing this line of contact. With a very slight tilting of the paraffin surface through an angle of only 2°, a drop of water slides easily over the surface of the paraffin.

If this same experiment is made by placing a drop of water on a glass slide covered with a monomolecular oil film, it is usually found that the drop does not slide off nearly so easily as it does from a paraffin surface. The drop only begins to move when the surface is inclined 6–10° and when this motion first occurs the contact angle at the advancing edge of the drop is much greater than that at the receding edge. This hysteresis or frictional effect indicates that the surface of the monomolecular film which has been in contact with the water has thereby been somewhat changed.

The contact angles observed with large stationary drops of water on glass covered by monomolecular oil films depend not only on the chemical composition of the adsorbed film but on the way in which this was applied to the surface. It is characteristic of oil films on water that the properties of the surface films of a definite substance are dependent only on σ and T, just as the properties of a given gas are dependent on p and T. Thus according to the nomenclature of the phase rule, this system is one that possesses two degrees of freedom.[6] Adsorbed films on solids sometimes show a similar behavior; for example, films of thorium and cæsium on tungsten have properties that are determined only by σ and T.

Oil films on solids, however, usually do not fulfill these conditions. A film having a given value of σ may have many different properties depending on the manner in which the molecules are attached to the underlying surface. It

[6] I. Langmuir, *J. Chem. Physics*, 1, 1 (1933).

would seem natural at first to suppose that a stearic acid film on glass has an upper surface which is essentially similar to that of a pure hydrocarbon. We might expect, therefore, that water would show a contact angle of 110° on a monomolecular stearic acid film. Actually, however, the angle is much less than this and it varies greatly with the manner in which the film is formed.

There appear to be two main factors which produce this effect. First, the closeness of spacing of the molecules on the surface determines what fraction of the upper surface consists of CH_3 groups.

The stearic acid films which are transferred to a glass surface from alkaline water show many unusual properties. A drop of water on such a film gives a contact angle of about 50°. This film is the only one which we have been able to find which is non-wettable by both water and mineral oils.

Dr. Blodgett has measured the angles obtained when drops of various liquids are placed on a trimolecular layer of stearic acid on glass. The results are: Squibb's Petrolatum 55.4°; benzol 48.0°; carbon tetrachloride 40.7°; hexane 1.5°; ethyl myristate 51.7°; water about 50°. The peculiar property of this trimolecular film of being non-wettable by both water and organic liquids results from the fact that the upper surface of the film consists almost wholly of CH_3 groups. The trimolecular film was chosen in these experiments because it has more uniform properties than the monomolecular film. Drops of Petrolatum on a monomolecular film gave a contact angle of 52.0; on a film 3 layers deep 55.4; 5 layers deep 55.2; and 7 layers deep 54.9. On the monomolecular layer there is considerably greater difference between the advancing and receding contact angles than in the case of the multimolecular films.

Films containing an even number of molecular layers when withdrawn from the water are wet because the carboxyl group is on top. When these films are dried, they become non-wettable by water indicating that the orientation becomes reversed as there is no longer any force to hold the carboxyl group on the surface.

If a stearic film is produced on glass by dipping the glass in a dilute film of stearic acid in benzol, this film shows against

both water and hydrocarbons a much smaller contact angle than do the films transferred to glass from a water surface. The molecules of stearic acid in a dilute solution in benzol diffuse one by one onto the glass surface. The first ones that arrive become firmly attached to the glass by their COOH groups. Experiments indicate clearly that at room temperature there is practically no surface mobility of these adsorbed molecules, so that each molecule remains attached to the point at which it first arrived at the surface. After a considerable fraction of the surface is thus covered, newly arriving molecules find increasing difficulty in finding suitable points of attachment on the glass. When the process is complete, there are still many portions of the glass not covered by COOH, but the vacant spaces are too small to permit the entrance of additional COOH groups. We can conclude that the last of the molecules to become attached to the surface are not able to attach themselves firmly to the surface because of the crowding by their neighbors. Such an adsorbed film is therefore non-homogeneous. Because of the larger spacing than in a close-packed film, the upper surface consists partly of CH_2.

Let us now consider the second effect which characterizes these films and which accounts for the large hysteresis observed. If a drop of water is placed on such a film on glass, some of the adsorbed molecules which are crowded by their neighbors and are therefore not held so firmly to the glass, can reverse their orientation so that the carboxyl group attaches itself to the water which lies on top of the film. The effect of the presence of the water drop is thus to modify the oil film so that the surface possesses a greater affinity for water and thus the receding contact angle becomes much less than the advancing angle.

The work of adhesion of a liquid for a solid, W_a, has been defined as the free energy change per unit area when a liquid is brought into contact with a solid. This is equal to

$$W_a = \gamma_2(1 + \cos B), \tag{9}$$

where γ_2 is the surface tension of the liquid and B is the contact angle which it makes when placed on the solid. If the contact angle is zero, $W_a = 2\gamma_2$ and is then equal to the work of cohesion for the liquid itself.

When one liquid (2) is spread out as a thin film (duplex film) on another liquid (1), the free energy change per unit area which again represents the work of adhesion is given by

$$W_L = \gamma_1 + \gamma_2 - \gamma_{12} = F_s + 2\gamma_2. \qquad (10)$$

If the first liquid spreads out on the second so as to form a zero contact angle, $F_s = 0$, and again $W_L = 2\gamma_2$.

Drops of Squibb's Petrolatum placed on slightly alkaline water covered by a stearic acid film give contact angles which vary with the surface pressure applied by a movable barrier. Thus, for example, with an external force $F_1 = 10$ dynes per cm., the contact angle B which is the supplement of the angle between the film on the water surface and the free Petrolatum surface, is 40.5°; with $F_1 = 20$, the angle is 37.8°; and with $F_1 = 30$ it is 33.8°. The values of F_s calculated from these (taking $\gamma_2 = 31.1$) are found to be constant and equal to -12.4. According to Eq. (10) the work of adhesion W_L is thus 49.8 and this value is independent of the state of compression of the film of stearic acid.

When these films of stearic acid are transferred to a glass surface to form a trimolecular layer, and a drop of Petrolatum is applied, the contact angle B is found to be 55.4° and this angle is independent of the external surface pressure that was applied to the stearic acid film while transferring it to the glass. The value of W_s calculated by Eq. (9) from this contact angle comes out to be 48.8, which agrees reasonably well with the value W_L obtained with a drop of Petrolatum on the film of water.

These results seem to indicate that in these close-packed films both on water and on glass, the upper surface consists of close-packed CH_3 groups whose properties are independent of the underlying solid or liquid substance. It is hoped that further studies of these contact angles, for the purpose of obtaining the work of adhesion of various liquids on this ideally smooth surface, should be of great value in helping to develop a better theory of the nature of liquid surfaces.

Lubricating Properties of Monomolecular Films.—The magnitude of the forces that hold monomolecular films on solid surfaces are important in connection with the problems of lubrication. With low bearing pressures and high speeds,

the viscosity of a lubricating oil is the principal factor in determining its quality, but with high pressures and slow speeds it has been known that other properties which are usually referred to as "oiliness" determine the lubricating value. Static friction between a round point and a plane surface corresponds to the extreme case where the velocity of movement is zero. The experiments that I have described [7] in which a glass rider is placed on a glass slide, prove that the static friction is profoundly modified by the presence of a monomolecular oil film. To obtain such films there must be certain groups in the molecule of the oil which attached themselves firmly to the material of which the bearing is made.

For many years measurements of static friction have been employed to measure oiliness, but the value of these data is doubtful. It would seem that an important element in problems of lubrication involves the rate of wear of the monomolecular films when subjected to rubbing by the opposing surface. There are some very simple yet striking experiments which illustrate the importance of this effect.

For example Dr. Blodgett has discovered that the experiment with the glass slide and the rider shows marked differences according to whether the monomolecular film is placed on the slide or on the rider. When both the slide and the rider are clean, the angle at which slipping occurs is usually greater than 60°; if a monomolecular film of a fatty acid is placed on the rider, the angle can usually be raised to 40° before any slipping occurs and then after a slip through a short distance the angle can be raised to about 60° without further slipping. When, however, a monomolecular film is applied to the glass slide, the rider slips off the slide at an angle of 6° to 8° whether or not any film has been applied to the rider. The essential difference between the application of the film to the slide and to the rider is that when sliding occurs, the point of contact continually moves to fresh parts of the surface of the slide, but it always remains at the same place on the rider. Thus a monomolecular film on the rider is almost immediately worn off and the friction rises, whereas on the slide, because of short duration of contact at any point, the

[7] I. Langmuir, *Trans. Faraday Soc.*, **15**, 62 (1920); *Gen. Electric Rev.*, **24**, 1025 (1921).

wear is negligible. This experiment then indicates that the monomolecular film on the rider is worn off by moving over a clean glass surface at a distance of only 2 mm.

In some other experiments made by Mr. Vincent Schaefer we have used as a rider a vertical shaft weighted with 300 grams and having at its lower end a rounded glass rod 3 mm. in diameter. This hemisphere of glass rested upon a glass slide covered by a monomolecular film of stearic acid. The slide was mounted on a miniature car which could be moved by a reciprocating motion along a track consisting of three V-shaped grooves in each of which a steel ball rested. In this way the point of contact between the glass rod and the slide could be made to move accurately back and forth along a given line. These experiments show that it took about 700 strokes across the slide before the coefficient of friction rose from 0.11 to 0.13. In another 200 strokes the friction rose to 0.24 and soon afterward seizing occurred. With a film 7 layers thick, the coefficient of friction did not increase perceptibly even after 4000 strokes.

Although this test can be made to measure accurately the wearing qualities of a monomolecular film, it still does not give the information we need to understand the problem of lubrication. We must provide a definite mechanism by which the damage done to the monomolecular film by wear can be repaired by new molecules which are carried mechanically to the surface.

Experiments showed that such substances as pure hydrocarbons, Petrolatum, carbon tetrachloride, etc., do not appreciably modify the static friction between clean surfaces of glass or of steel. Very minute amounts of active substances such as fatty acids, even as little as 1 part in 100,000, added to a pure hydrocarbon and applied to the slider can produce a monomolecular film on the slider and can thereby cut down the static friction.

It seems desirable to devise a test for the effect of the additions that may be used which will involve not only the stability of the monomolecular film that is formed but also the rate at which the film is repaired by the bringing in of new molecules of the active substances to the interface by the hydrocarbon solution which is dragged by friction to the interface.

For this purpose Mr. Schaefer and I have devised the following apparatus. A small steel plate or table is mounted on knife edges and suspended from another set of knife edges so that the table can move horizontally with practically no static friction. The glass slide to be tested is supported on the table by a wedge-shaped plate in such a way that the glass slide is inclined 5° from the horizontal in a direction at right angles to that in which the table can move. A vertical shaft carrying a glass or metal hemisphere (rider) at its lower end presses down against the inclined glass surface and is made to rotate once per second by a telechron motor. Additional weights up to 400 grams can be applied to the shaft.

When the glass slide and the rider forming the lower end of the shaft are both clean so that there is no slipping, the rotation of the rider about the vertical axis, because of the inclination of the slide causes the table carrying the slide to move at a uniform rate so that, after a certain time t, it has travelled a definite distance. Horizontal forces may then be applied which tend to oppose this motion. Until the forces are made sufficiently great to cause slipping, however, the time t is not increased, but with greater forces some slipping occurs and therefore t does increase. Finally with a sufficiently large force so much slipping occurs that the table does not move at all, so that t becomes infinite. Thus by applying different horizontal forces, different values of t are obtained; each horizontal force divided by the vertical force applied on the rider gives the coefficient of friction. In analyzing these experiments the coefficient of friction is plotted as a function of $1/t$.

Tests of this kind are particularly interesting when a series of solutions of different strengths, containing an active substance in an inert substance like pure hydrocarbon are used. As little as 1 part per 100,000 of fatty acids in a hydrocarbon exerts a marked effect in reducing the friction; with 1 per cent. the friction falls to about 0.05 and remains about constant for higher concentrations.

Some preliminary studies have been made using different materials for the slider and the rider. Marked differences are obtained for different materials. Although these results are preliminary, it is hoped that data will be obtained which pro-

vides a better basis for an understanding of the fundamental phenomena of lubrication.

Interfaces between Oil and Water.—The theory of the expanded films which I have previously outlined indicates that these films should be regarded as duplex films having an upper and a lower surface, the lower surface being essentially an interface between a hydrocarbon and water.

It would seem therefore that the phenomena at the interface between oil and water should in many ways be simpler than those characteristic of monomolecular oil films on water. Within the last year therefore, Dr. Blodgett and I have been endeavoring to evolve a technique suitable for the study of monomolecular films at the interface between oil and water.*

For this purpose we have used Petrolatum in which we have dissolved small amounts of stearic acid. The concentrations, which we shall denote by w, expressed in parts by weights, ranged from 10^{-5} to 10^{-2}. Small amounts of these solutions placed upon water show phenomena of great interest. The results depend markedly on whether the water is acid or alkaline. In the case of alkaline water the presence of minute traces of calcium salts profoundly affect the results. The amounts of calcium that can remain in solution, even after sodium carbonate has been added to the water, may be enough to have a marked effect on the phenomena. In most of our experiments with alkaline water we have used 0.02 normal NaOH to which has been added enough sodium carbonate to make the solution 0.02 normal with respect to this substance also. A 10-fold increase in the concentration of these substances has relatively little effect on the results obtained. With much lower alkalinity, the results become erratic because of absorption of carbon dioxide from the air.

If very dilute solutions of stearic acid in Petrolatum (w ranging from 10^{-5} to 5×10^{-5}) are placed on alkaline water, lenses are formed which increase gradually in diameter until they reach a final limiting value. Until the diameter is

* All the experimental work which I shall describe is that of Dr. Blodgett, who has also contributed much to the theoretical interpretation. When the work is completed, the results will be published jointly by Dr. Blodgett and myself. The results that I shall give here are meant to constitute a preliminary announcement of this joint work.

about three-quarters of its final value, the rate of increase of diameter with time is such that a plot on semilogarithm paper a straight line is obtained. The slope of this line is found to be accurately proportional to w^2 and it increases rapidly as the temperature is raised.

A theoretical study has indicated that the rate of growth of these lenses is determined by the rate at which the stearic acid can diffuse to the interface. A mathematical analysis, which involves the use of Fourier's series, differs from that of the usual diffusion problem in that the diffusion takes place through a body whose dimensions are continually changing, the volume, however, remaining constant. The hypothesis is made that each molecule of stearic acid which reaches the interface causes an increase of the interfacial area by an amount equal to a. This theory seems to be in complete accord with experiment over the whole range of diameters up to the final limiting value. When the diameter is not too large, the theory gives the simpler expression

$$d \ln A/dt = n^2a^2D/\pi, \tag{11}$$

where D is the diffusion coefficient, n is the initial concentration (before spreading begins) and A is the area of the lens at any time t. A comparison of this equation with experimental data therefore enables us to determine the absolute value of the diffusion coefficient D. Experiments have shown

$$\log_{10} D = 1.985 - 2640/T, \tag{12}$$

where T is the absolute temperature. The temperature coefficient of D is found to be the same as that of the viscosity of the Petrolatum.

The final limiting area of a lens of a given volume increases in proportion to the concentration and corresponds to $a = 88 \times 10^{-16}$ cm.^{2} per molecule of stearic acid at the interface (assumed molecular weight 284). This is about four times the area of the molecules in a condensed film on water.

With solutions stronger than $w = 10^{-4}$ the lenses spread at a rate too fast to measure and as they no longer remain circular it is difficult to measure the area accurately.

When concentrations from 0.001 to 0.006 are used, the

films become so thin that iridescent colors appear. This color may be used to measure the thickness t of the film and from this the area per molecule can be calculated by the equation,

$$N\rho wat = M, \tag{13}$$

where M is the molecular weight, N the Avogadro constant 6.06×10^{23}, and ρ is the density of the lens.

These interference colors are produced when the thicknesses of the oil film are definitely related to the wave-length of the light. An empirical method has been developed by which the thickness can be measured within about 1 or 2 per cent. by matching the color of the film against that of a "comparison film." A "comparison oil" may be made by oxidizing a good grade of lubricating oil, from Pennsylvania petroleum, in an open dish on a hot plate, raising the temperature until the oil smokes. This heating is continued until, when a drop of the oil is placed on water, the color obtained corresponds to the first order of yellow, that is, the thinnest film which shows appreciable color. A drop of known volume (from a calibrated pipette) is then placed on water on a large tray. By moving a barrier the area of this film can be decreased and as this is done the color changes from the original yellow through a series of other colors. In this way the color can be brought to match that of any other colored oil film whose thickness it is desired to measure. The thickness of the film of the comparison oil can always be determined by dividing the volume of the drop by the area occupied by it on the tray as determined by the position of the barrier. When the color of the comparison film is the same as that of the film to be studied, then the thickness is the same if the "order" of the color is the same and if the refractive index of the oil is the same. It is easy to tell whether the order is the same by seeing whether the comparison oil and the disc are the same in color when viewed at several different angles of incidence.

This method of measuring the thicknesses of various thin films has been found to be extremely convenient. When applied to Petrolatum films on alkaline water it gives for a, the area per molecule, the same value (88×10^{-16} cm.^{2}) as that obtained from the discs of dilute solutions, $w = 10^{-5}$.

Thus the monomolecular film at the interface of alkaline water has no appreciable solubility in the Petrolatum. When small amounts of calcium are present in slightly alkaline water, the area per molecule of the monomolecular film at the interface becomes roughly one-quarter as great as in the absence of calcium so that the area per molecule is probably about 20×10^{-16} cm.^{2} The films at the interface are also solid instead of liquid as when calcium salts are absent. This can be seen strikingly by introducing, by means of a capillary tube, a little of a dilute solution of a calcium salt just under a thin lens of Petrolatum containing stearic acid ($w = 5 \times 10^{-5}$) which is resting on water containing $N/100$ sodium hydroxide. Where the calcium comes into contact with the interface it causes the film to become about four times thicker. This thickened area can then be pushed around by a platinum wire very much as a cake of ice can be moved over the surface of a lake. The interfacial film in presence of calcium thus becomes a 2-dimensional solid.

On acid water ($N/100$ HCl) it frequently takes hundreds or even thousands of times as much stearic acid in the Petrolatum to produce a given amount of spreading in the lens. This is due to a solubility of the monomolecular film on acid water in the Petrolatum. This solubility increases rapidly as the temperature increases.

Let me describe the experimental results that Dr. Blodgett has obtained at a temperature of 33° C. When a few cubic centimeters of a solution of stearic acid in Petrolatum of a concentration less than $w = 0.0031$ are placed upon $N/100$ HCl, lenses are formed which show a contact angle more than about 7°. This angle increases up to about 55° as w is made to decrease towards zero. From these measurements it is possible to calculate F_{12}, the spreading force at the interface due to the adsorbed film of stearic acid. The amount of stearic acid adsorbed at this interface under these conditions is negligible compared to the amount that remains dissolved in the Petrolatum so that equilibrium establishes itself quickly.

With a concentration $w = 0.0031$, the value F_{12} has reached 11.8. With a concentration greater than $w = 0.0034$, $F_{12} > 12.2$ which makes the spreading coefficient $F_2 > 0$, and the lens tends to spread indefinitely. This large increase

in area and the resulting increased amount adsorbed withdraws stearic acid from the Petrolatum solution until the concentration is reduced to a critical value w_0 which is equal to 0.0034 at 33° C. The area to which these duplex films spread is thus proportional to the excess of the original concentration w over w_0.

From the slope of the straight line obtained by plotting the area against w, the area per molecule, a, can be measured. The experiments show that $a = 64 \times 10^{-16}$ cm.^{2}, this being calculated by assuming that the molecular weight of stearic acid is 284.

When w is increased to about 0.006, the duplex films become so thin that interference colors are observed. With $w > 0.010$ the films become too thin to show interference colors. In this range from 0.006 to 0.010 the thickness of the film can be measured by color, using a comparison film, and the values of a calculated by Eq. (13) are again found to be equal to 64×10^{-16} cm.^{2}. In these experiments the lens or duplex film has been applied to the acidulated water on which no film is present so that $F_1 = 0$.

Further experiments with duplex films were then made by placing on the water monomolecular films of stearic acid under a known surface compression so that F_1 was maintained at a given value such as 2, 4, or 6 dynes cm.$^{-1}$. Small amounts of the solution of stearic acid in Petrolatum were then applied and the thicknesses of the duplex films were determined by the color. For any given value of F_1 the reciprocal of the thickness gives a straight line when plotted against w. The intercept of this line on the w-axis gives the critical w_0 corresponding to this value of F_1. The slope of the line gives us the value of a. Since with these duplex films $F_s = 0$ and since γ_2, the surface tension of the upper surface of the Petrolatum, is unchanged by the presence of stearic acid, it follows that $F_{12} = 12.2 + F_1$.

We have previously shown that by measuring contact angles, the relation between F_{12} and w_0 can be obtained for values of F_{12} ranging from 0 up to 11.8. The data obtained with duplex films for different values of F_1 then permit F_{12} to be obtained as a function of w_0 for values of $F_{12} > 12.2$. Although the experimental methods are entirely different, the two curves appear to be parts of a single smooth curve.

According to Gibbs' equation (8) we can calculate σ, the number of adsorbed molecules per unit area, from the variation of log w with F. The value of a found in this way at the point where $F_1 = 0$ ($F_{12} = 12.2$) gives $a = 127 \times 10^{-16}$ cm.^{2} which is twice the value obtained from the slopes of the plots of the reciprocal of the film thickness against w. Measurements at all points of the curves show the same 2 to 1 relationship of the values of a by the two methods. This discrepancy disappears, however, if we assume that the stearic acid in the Petrolatum solution exists as double molecules which are sufficiently non-polar for Raoult's Law to be applicable. On this basis the area a obtained by the use of Gibbs' equation is the area occupied in the interface by the amount of stearic acid which constitutes a molecule in the Petrolatum phase. Thus if we let a be the area occupied by the amount of stearic acid corresponding to a single molecule of the molecular weight 284, we must divide the calculated weight by 2.

A justification of the assumption that the stearic acid exists as double molecules in solutions of hydrocarbons is obtained by studies of the solubilities of stearic acid at various temperatures. According to Raoult's Law, the logarithm of x, the mole fraction of the stearic acid in the saturated solution, should be a linear function of $1/T$, and the slope of this line should correspond to the heat of fusion of the stearic acid. Experiments on the solubility of stearic acid in tetradecane, $C_{14}H_{30}$, and in decahydronaphthalene, $C_{10}H_{18}$* have shown that the slopes of the straight lines that were obtained correspond to twice the heat of fusion of stearic acid as given by Garner and King.[8] This also indicates that the stearic acid molecules in solutions in hydrocarbons exist as double molecules. Measuring the solubility of stearic acid in Petrolatum, the experiments indicate again double molecules if the average molecular weight of the Petrolatum is taken to be 600.

We have seen from our analysis of the F–a diagrams of expanded films that the equation of state of adsorbed films at the interface between oil and water should be given by Eq.

* This substance was kindly supplied to us by Dr. W. Carothers of the DuPont Experimental Station.

[8] W. E. Garner, A. M. King, *Jour. Chem. Soc.* (1929), 1849.

(6). If this is so, then by combining this equation with Gibbs' equation (8), and assuming the existence of double molecules in the solution, it should follow that $2 \log F_{12} - \log w_0$ should be a linear function of F_{12}, and that the slope of this line should be proportional to the value of a_0 given by Eq. (6). When the experimental data which give F_{12} as a function of w_0 are replotted using $(F_{12})^2/w_0$ as ordinate on semi-logarithmic paper against F_{12} as abscissa, a good straight line is obtained, the slope of which gives the value $a_0 = 25 \times 10^{-16}$ cm.^{2}.

Similar experiments have been carried out at a series of temperatures lower than 33° C. At each temperature it is found that with concentrations below a certain critical value w_j, the data are in agreement with Eq. (6) with the same value of a_0. All of these results at temperatures ranging from 10° to 33° may be summarized by the equation

$$\log_{10} [F_{12}^2/w_0] = -0.465 + (1740 - 15.8F_{12})/T. \quad (14)$$

At each temperature a kink occurs in the curves expressing F_{12} as a function of w_0, when $w_0 = w_j$, and for values of w_0 above this critical value a is found to be constant and equal to approximately 25×10^{-16}. In other words, the adsorbed film at the interface between the oil and water changes suddenly from a 2-dimensional gas to a 2-dimensional liquid. This transition seems to be entirely similar to that which we have concluded must exist in the case of expanded films of fatty acids on dilute acids.

This sudden change of state of the stearic acid film at the interface between oil and water produces some striking phenomena. For example, if a solution of stearic acid in Petrolatum of a concentration $w = 0.0023$ is placed upon acidulated water at 23° C., a relatively thick lens is formed which shows a contact angle of about 10°. On cooling the water to 19° the lens expands to several times the original area. Abrupt changes in the color of the duplex films formed with somewhat more concentrated solutions are observed at certain critical temperatures. On cooling to these temperatures the films suddenly expand so that the thickness decreases to less than one-half their original thickness. All of these phenomena are completely explainable by this transition between the liquid and gaseous 2-dimensional film.

The duplex films produced on either alkaline or acid water by solutions of stearic acid in Petrolatum are inherently metastable films for they gradually tend to break up into small lenses which show contact angles of about 6° or 8°. Fortunately, however, this change to a thermodynamically more stable form occurs sufficiently slowly so that measurements of the metastable equilibrium are possible.

The breaking up of the duplex film into lenses is a phenomenon of considerable interest. During this process the duplex film and the small lenses formed shed a certain amount of their stearic acid onto the surrounding water surface. Within a confined area this results in the building up of a small external surface pressure measured by F_1. At a temperature of 33° the shedding of the stearic acid by the lens begins at a definite concentration $w = 0.0031$, so that it is only above this concentration that the metastable form of the lenses exists. With a concentration $w = 0.0033$ a lens is formed which gradually spreads into a thin disc. This soon becomes thicker near its outer boundary and finally peels back to form one or more small lenses leaving a film of stearic acid on the water.

Cary and Rideal [9] have shown that pure fatty acids in their liquid or solid states, when applied to $N/100$ HCl cause no reduction in the surface tension of the water until a definite temperature is reached and that above this temperature F_1 (the reduction of surface tension) increases linearly with the temperature. No theoretical reason was given for this linear increase with temperature.

A study of the vapor pressures of the liquid fatty acids for which data are available indicates that for $N > 10$ the vapor pressures should be given by the equation,

$$\log_{10} p_L = 11.25 - (2128 + 83.7N)/T, \qquad (15)$$

where p_L is the vapor pressure of the liquid in baryes and N is the number of carbon atoms in the molecules of the fatty acid. For stearic acid ($N = 18$) we thus have

$$\log_{10} p_L = 11.25 - 3621/T. \qquad (16)$$

[9] Cary and Rideal, *Proc. Roy. Soc.* (A), **109**, 301, 318, 331 (1925).

The vapor pressure of solid stearic acid can then be calculated from Garner and King's [8] values of the melting point and from the heat of fusion:

$$\log_{10} p_s = 20.76 - 6888/T. \qquad (17)$$

A condensed film of stearic acid on acidulated water under no external surface pressure (that is, for $F_1 = 0$) must exert in the air above it, under equilibrium conditions, a definite partial pressure p_0 which should vary with the temperature according to an equation of the form

$$\log_{10} p_0 = A_0 - B_0/T. \qquad (18)$$

For such a condensed film we may take a = constant and therefore σ, which is equal to $1/a$, should be placed constant in Eq. (8). Integration then gives

$$\ln (p/p_0) = aF/kT, \qquad (19)$$

where p_0, which appears as an integration constant, must be the same as the p_0 of Eq. (18) since it is the partial pressure of the stearic acid in a film for which $F = 0$.

If now we apply Eq. (19) to the case where the film on the water is in equilibrium with solid stearic acid, p becomes equal to p_s. Thus combining Eqs. (17) and (18) with Eq. (19) and introducing the value $a = 25 \times 10^{-16}$ and $k = 1.37 \times 10^{-16}$, we find that the spreading force F produced by solid stearic acid is given by

$$7.90F = (20.76 - A_0)T - (6888 - B_0). \qquad (20)$$

Thus the linear relation between F and T found by Cary and Rideal depends, by Gibbs' equation, upon the fact that the film produced is a condensed film for which a is approximately constant.

Now Cary and Rideal have found that the linear relation between F and the temperature t is given by

$$F = 0.553(t - 17) \qquad (21)$$

and that the coefficient 0.553 is approximately the same for all the saturated fatty acids.

Dr. Blodgett has placed upon acidulated water a thin paste of stearic acid in Petrolatum obtained by cooling a solution saturated at a higher temperature. When the temperature is raised, this drop of paste begins to shed stearic acid at a definite temperature. All such measurements (including Cary and Rideal's) are apt to be greatly affected by the presence of traces of impurities. By the technique that we have developed it has become possible, however, to allow all traces of impurities to escape before the final measurements are made. In this way it has been found that the temperature at which the saturated solution of stearic acid begins to shed its stearic acid as a monomolecular film is 28° C. and not 17° as given by Cary and Rideal. For myristic acid, however, Dr. Blodgett's results are in good accord with Cary and Rideal's. Therefore in place of Eq. (21) we believe that the equation which expresses the spreading force of solid stearic acid should be given by

$$F = 0.553(T - 301). \tag{22}$$

Comparing this equation with Eq. (20) we find that $A_0 = 16.39$, $B_0 = 5573$. Substituting these in Eq. (18), and introducing the value p_0 into Eq. (19), we finally obtain

$$\log_{10} p = 16.39 - (5573 - 7.9F)/T. \tag{23}$$

This equation gives the partial vapor pressure of a condensed film of stearic acid on acidulated water as a function of the temperature T and of the applied external surface pressure F.

From Raoult's Law applied to the double molecules and from our experimental data on the solubility of stearic acid in Petrolatum the partial pressure of stearic acid over any solution of this substance in Petrolatum is given by

$$\log_{10} p = 10.908 - 3533/T + (1/2) \log_{10} w. \tag{24}$$

The true thermodynamic equilibrium, therefore, between any lens of stearic acid in Petrolatum and a surrounding water surface can therefore be obtained by eliminating p between Eqs. (23) and (24) giving

$$\log_{10} w = 10.964 - (4080 - 15.8F)/T. \tag{25}$$

I have described these preliminary results of our studies of oil lenses containing stearic acid in considerable detail because I believe that the methods we have worked out should lay the foundation for an exact thermodynamic analysis of the energy relationships of adsorbed films on water and on the interfaces between oil and water. A further analysis of these data should make it possible to get detailed knowledge of the forces acting between these adsorbed molecules.

I have laid a good deal of emphasis on the adsorbed films at the interface between oil and water because these have, I believe, far more practical significance than the films that can be formed at the surface between water and air. The results should be of interest in connection with any study of emulsions, but I believe they will be particularly useful in the field of biology. The behavior of living cells depends very greatly upon what takes place in the cell walls which must depend fundamentally upon the phenomena at the interface between two liquids and upon the modification of this interface by the presence of adsorbed substances. It is well known by biologists that living cells require a delicate balance between the concentrations of sodium, potassium, calcium, magnesium and hydrogen ions in the solutions in which they are immersed. In our studies of the interface between oil and water we have found a similar sensitiveness to the effects of these ions, and if the methods that we have evolved can be applied by the biologists in the study of their problems, I feel that our work has been amply rewarded.

Color Reaction of Vitamin A.—EUGENE ROSENTHAL and JOHN ERDELYI (*Biochem. J.*, 1934, XXVIII, 41–44) describe a new color reaction of natural vitamin A. Alcohol-free, absolute chloroform is used as the solvent. When this test is applied to cod liver oil, from 0.1 to 0.5 cc. of the oil is dissolved in 1 or 2 cc. of chloroform. The resulting solution is mixed with 1 cc. of 0.5 per cent. of catechol in chloroform and 2 or 3 cc. of a cold saturated solution of antimony trichloride in chloroform. The mixture is *immediately* heated for 1 to 2 minutes in a water bath at a temperature of 60° C. An initial blue color changes during the heating to an intense violet-red hue. This reaction is not given by carotene (the precursor of vitamin A) or by irradiated ergosterol (synthetic vitamin D). Ergosterol yields first a pink, then a blue color, even in the absence of catechol and without heating. This reaction may be applied for the quantitative determination of vitamin A, using a colorimeter and 0.01 per cent. solution of potassium permanganate as the standard. The readings must be made promptly, for the color of the "unknown" fades into brown in a short time.

J. S. H.

Silicosis Among Granite Quarriers.—J. J. BLOOMFIELD and WALDEMAR C. DREESSEN (*Public Health Reports*, 1934, XLIX, 679–684) have made a study of the occurrence of the industrial disease silicosis among 150 workmen, of whom 38 per cent. were drillers, in a typical Vermont granite quarry. The drillers, who used dust-producing pneumatic tools, were exposed to an atmosphere containing between 36,900,000 and 144,400,000 dust particles per cubic foot of air, the other workmen to an atmosphere containing 5,800,000 dust particles per cubic foot. This granite dust contained 35.2 per cent. of quartz (silica). The average diameter of the dust particles never exceed 6 microns, was less than 2 microns for 75 per cent. of the particles, and less than 1 micron for 10 per cent. of the particles. Physical examinations and X-ray studies of the thorax demonstrated that pathological changes due to dust were limited to drillers. Silicosis existed in one-half of the drillers with an exposure of 5 to 19 years, and in four-fifths of the drillers with an exposure of more than 20 years. The only solution of this problem is the removal of the dust at its source, the drills.

J. S. H.

REPORT ON THE WORK OF THE BARTOL RESEARCH FOUNDATION, 1933-1934.*

Made to the Membership of The Franklin Institute.

BY

W. F. G. SWANN, D.Sc., Director.

INTRODUCTION.

A few years ago, physics enjoyed contentment in the belief that there were but two fundamental entities in nature, the electron and the proton, the former, the unit of negative charge, being so small that three million million of them laid side by side would take up no more than a centimeter, and the latter, the unit of positive charge, being even two thousand times smaller. It was the duty of these two entities to do everything, to form the bricks out of which the atoms are built, to emit light, heat, electric waves, and every other kind of radiation, to serve as the carriers of electric currents, and in general to attend to all the phenomena of nature. When these slaves of the universe seemed to ask for anything to aid them in their task, we gave them the electromagnetic equations. When, failing to find in the electromagnetic equations a solution for all of their difficulties, they raised an appeal for more assistance, we grudgingly gave them light quanta, or photons, and then took away the electromagnetic equations, except to the extent of leaving them, as it were on guard, as a sort of watchman to see that the electrons and protons did not get away with too much with the light quanta. And then, only a year or two ago, nature, as though relenting her demand that the poor proton and electron should build the universe without straw, suddenly hurled out of the nucleus of the atom for their assistance two new entities, the neutron and the positron. The poor physicist, bewildered by the lavishness of this donation to his stock in trade is now busy finding how best to make use of these new helpers in his thought-structure. He

* Presented at the Stated Meeting held Wednesday, April 18, 1934.

is like a small college which has just been left ten million dollars. He is torn between respect for the conventions of the past and a desire to make the most of his new opportunities. Intuition—that unborn embryo begotten of the experiences of the past, vaguely conscious in its new-found life of the truths of the future—intuition urges him on to try all sorts of speculations. The ghosts of his professional ancestors arise and warn him to be careful, and not wander too far from the beaten track. As in most revolutions, however, there is apt to be an interchange of importance between certain elements in the new and old regimes. Some of the dignitaries of the older regime have to take a back seat in the councils of the new, and some of the upstarts of the old order become the leaders of the destinies of the new.

Now, one of the upstarts of the older generation was the mass-energy law, a law born of the theory of relativity, and to the effect that there is an intimate relation between mass and energy in the sense that if by any means mass, in the sense that a particle has mass, is caused to disappear, energy makes its appearance in amount proportional to the mass which has evaporated, the factor of proportionality being the square of the velocity of light, so that if E is the energy which appears, m the mass which disappears, and c the velocity of light,

$$E = mc^2. \tag{1}$$

The importance of this relation in the economy of nature is tremendous. It tells us that the annihilation of a single drop of water would produce enough energy to provide 200 horse-power for a year. It tells us that if an ounce of lead could be converted into gold, the value of the energy which would be liberated to account for the mass which we know would disappear in the transmutation would be enormously greater than the value of the gold produced. It is to this law that we look to provide the enormous radiation of energy by the sun and stars; for we believe that those stars are devouring their very substance to pay that tax of radiation to the universe which nature demands of them as payment for permission to shine with such great brightness.

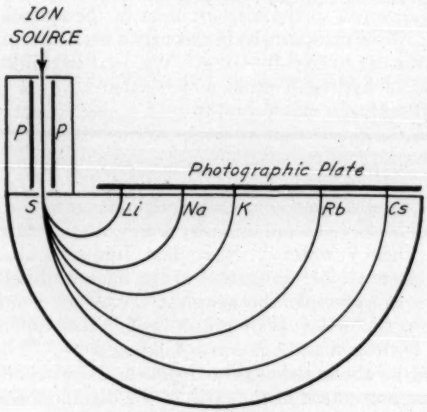
Although the equivalence of mass and energy plays such an important part in our theories of the economy of nature, the

truth of that equivalence has remained until recently without direct experimental proof. An experiment verifying its truth in one particular case has been carried out at the Bartol Foundation by Dr. Kenneth Bainbridge, and was one of the last experiments which he performed here before departing for Cambridge, England, on a Guggenheim fellowship. Presently, I shall describe the nature of the experiments by which Dr. Bainbridge arrived at the verification cited; but it will be convenient first to describe certain other investigations which lead up to it.

EXPERIMENTS CONCERNING ISOTOPES.

Dr. Bainbridge's apparatus has been described in detail in former reports. It will be recalled that if a charged atom or molecule, an ion as it is called, of definite velocity is caused to pass through a slit *S*, Fig. 1, and enter a magnetic field sup-

FIG. 1.



posed perpendicular to the plane of the paper, its path will be bent into a semicircle whose radius is proportional to the mass of the atom concerned, and inversely proportional to the charge which it carries. If a train of such ions is caused to fall upon a photographic plate it produces an effect which, on

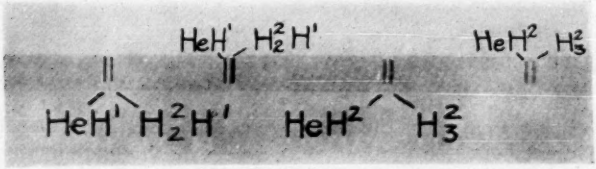
development, results in an image of the slit through which the ions originally came. Thus, in Fig. 1, the different atoms Li, Na, K, Rb, Cs, deposit themselves at successively greater distances from the slit *S*. The device by which the ions are allowed to pass from the source to the slit *S*, and which has been described before, insures that they enter the magnetic field with equal velocity, so that if they have equal charges, the distances from the slit at which they deposit themselves may be taken as proportional to the masses.

A great deal of importance attaches to the existence of what we call isotopes. Formerly it was thought that a substance like mercury, for example, was composed of atoms which were all alike, but we now know that it is composed of six different kinds of atoms, all different in weight. Such different kinds of atoms of the same element are called isotopes of the element, and most of that portion of Dr. Bainbridge's work, which has been covered in former reports, has been devoted to the measurement of the masses of these isotopes. Now comparatively recently a very interesting new isotope was discovered by Urey. We used to think that the only kind of hydrogen atom which existed was a hydrogen atom containing a single proton and a single electron. We now know, however, that hydrogen atoms exist with a weight approximately twice that of ordinary hydrogen. Such a hydrogen atom is denoted by the symbol H^2. When one of these hydrogen atoms combines with oxygen to form water, this water is heavier than ordinary water, and is known popularly as "heavy water." Now, last June, Dr. Bainbridge made an accurate determination of the mass of this hydrogen isotope.[1] In principle the simplest procedure would be to obtain on the same photograph a line corresponding to ordinary hydrogen and one corresponding to H^2. The second one would be about twice as far from the slit as the first one, and the measurement of the ratio of the distances would give the mass of H^2 in terms of H^1. However, such a procedure would not be very accurate because it is difficult to fix the position of the slit with accuracy, to allow for the stretching of the photographic film in development, for uncertainties of the

[1] "Comparison of the Masses of H^2 and Helium." *Phys. Rev.*, **44**, No. 1, 57, July 1, 1933.

magnetic field, etc. Happily, however, one can obtain in a gaseous discharge which is the source of the ions all sorts of atomic and molecular entities built up out of atoms of known weight, and among these he may find one which is very near to the expected weight of H^2, or of some other entity in which H^2 plays a part. In this case, the spectrum will contain two lines close together, one of them involving the weight of known things, and the other involving the weight of H^2. By measuring the small distance between these two lines, one may then with accuracy obtain the weight of H^2 in terms of the weights of known things. Thus, for example, a molecule composed of helium of mass approximately 4, and an atom of hydrogen of mass approximately 1, would have a mass of approximately 5. On the other hand a molecule composed of two atoms of heavy hydrogen and one of ordinary hydrogen would also have a mass approximately 5. In the spectrum shown in Fig. 2, which was taken by Bainbridge, we see close

FIG. 2.

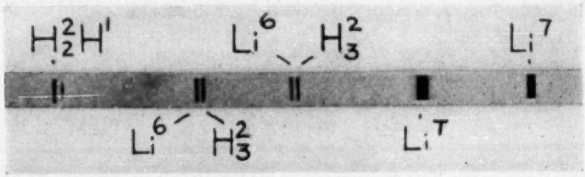


together two lines, one corresponding to HeH^1, and the other to $H_2{}^2H^1$. The difference between these two lines gives us the mass of H^2 in terms of the mass of H^1 and the mass of helium. Now, both Bainbridge and Aston had determined the mass of helium in terms of H^1, a matter which, as regards Bainbridge's measurements, I reported last year, and Aston had measured helium in terms of the standard unit, oxygen, so that it was possible to determine the mass of heavy hydrogen. Several other determinations were made, according to the same general principle. Thus in the discharge tube there was a molecule of approximately 6 units of weight and composed of one atom of helium and one of heavy hydrogen. This molecule is HeH^2.

There was also a molecule composed of three atoms of heavy hydrogen, having a total weight of about 6. This molecule is H_3^2. The two molecules gave lines close together, and from their difference it was again possible to determine H^2 in terms of known weights. Other determinations were made by a comparison of HeH^1 and $H_2^2H^1$, both of these molecules having a weight of approximately 5. Still another comparison was made between the molecule HeH^2 and the molecule H_3^2, each of these molecules having a weight of approximately 6. The net result of all of these was to give the mass of heavy hydrogen as 2.01363 ± 0.00008, with oxygen taken as 16 for a standard.

Having obtained the mass of heavy hydrogen, Bainbridge used this to obtain the masses of the two lithium isotopes, whose masses are approximately 6 and 7.[2] Fig. 3, is the

FIG. 3.



spectrum from which the results were obtained. The molecule composed of three atoms of H^2 has a weight of approximately 6, and so gives a line very close to that given by Li^6. The difference between these lines thus gives Li^6 in terms of the now known H^2. The fact that two pairs of lines corresponding to Li^6 and H_3^2 are shown simply means that two exposures were taken on different portions of the photographic plate. The spectrogram also contains the lines due to Li^7 and serves thus for a determination of its mass but with somewhat less accuracy. In terms of oxygen taken as 16 the results were, for Li^6, 6.0145 ± 0.0003, and for Li^7, 7.0146 ± 0.0006.

Having obtained the mass of Li^7, Bainbridge[3] was able to

[2] "The Masses of the Lithium Isotopes." *Phys. Rev.*, **44**, No. 1, 56–57, July 1, 1933.

[3] "The Equivalence of Mass and Energy." *Phys. Rev.*, **44**, No. 2, 123, July 15, 1933.

utilize it for the very important verification of the mass energy relation to which I have referred. Within the last two or three years, Cockcroft and Walton, in England, have shown that if protons having an energy corresponding to that obtained from an electrical potential difference of 270 kilovolts, are fired at lithium, alpha particles of energy corresponding to 8.62×10^6 volts are emitted. It is believed that the mechanism of the process is one in which occasionally a lithium atom of mass approximately 7 captures a proton of mass 1 to produce an entity of mass 8 which then explodes giving rise to two alpha particles, each of mass 4. If Li^7, p, and α refer to the masses of the Li^7 atom, the proton, and the alpha particle, the story is told in a simple and approximate form by the equation

$$Li^7 + p = 2\alpha.$$

However, a recognition of the mass energy relation would require us to amplify this expression in such a manner as to associate with each of the energies involved a mass equal to that energy divided by c^2. Our equation should therefore be

$$Li^7 + p + (\text{energy of proton})/c^2 = 2\alpha + 2\,(\text{energy of } \alpha \text{ particle})/c^2,$$

which may be written

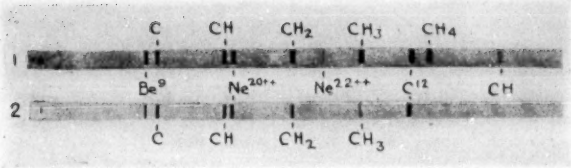
$$Li^7 + p - 2\alpha = (2 \times \text{energy of } \alpha \text{ particle} - \text{energy of proton})/c^2. \quad (2)$$

Now the masses of the alpha particle and of the proton are known from Aston's measurements, and the mass of Li^7 is now known from Bainbridge's measurements, so that we find for $Li^7 + p - 2\alpha$, the value 0.0181 ± 0.0006. Hence, if the mass energy relation is true, we should find this equal to the right-hand side of (2). The right-hand side when worked out comes to 0.0182, so that within the limits of accuracy of the experiments, the mass-energy relation is verified.

Passing over rather rapidly certain other important measurements which Dr. Bainbridge has obtained during the year, I may show Fig. 4,[4] which represents spectrograms from

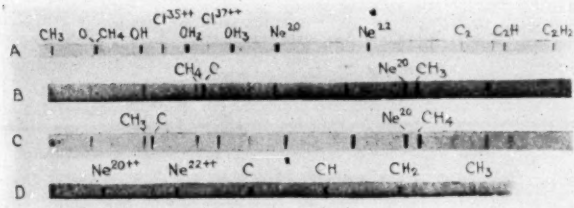
[4] "The Mass of Be^9 and the Atomic Weight of Beryllium." *Phys. Rev.*, **43**, No. 5, 1–20, March 1, 1933.

FIG. 4.



which he obtained an accurate measurement of the mass of Be^9 in terms of the known mass of carbon, by comparing each of them with the mass of marsh gas, CH^4. I may refer also to Fig. 5,[5] which again I will not describe in detail and which concerns the masses of Ne^{20}, Ne^{22} and B^{11}.

FIG. 5.

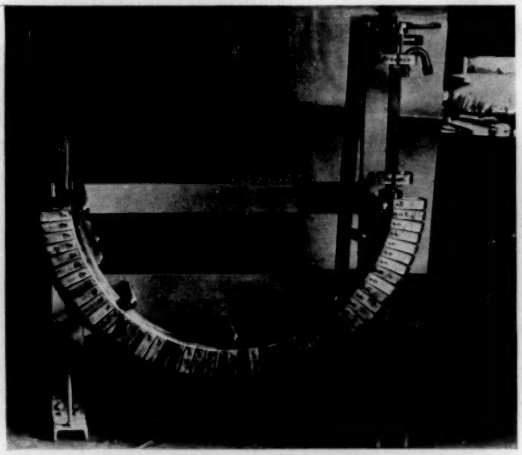


I will close this description of Bainbridge's work by showing Fig. 6, a photograph of a new form of mass-spectrograph in which the magnetic field is produced by permanent magnets arranged in a semicircle, and which is designed for very high resolution so as to measure mass differences of extremely small amount. The diameter of the semicircle is one meter. Just as the atom may exist in different energy states as regards that outer electronic structure which is responsible for the emission of light radiation, etc., so we believe that the nucleus itself may exist in various energy states; and, corresponding to these different states, the

[5] "Masses of Ne^{20} and B^{11}. The Mass of Ne^{22} and the Disintegration of F^{19}." *Phys. Rev.*, **43**, No. 6, 424–427, March 15, 1934.

nucleus should have different masses. There may, in fact, be what the physicist calls a fine structure to the mass spectra of even the isotopes, in the sense that every spectrum line produced by an individual isotope should, on examination, be seen to be composed of a number of fine lines close together each one corresponding to the mass associated with a par-

FIG. 6.

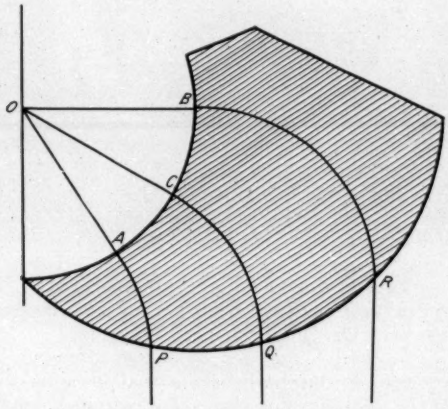


ticular energy state in which the nucleus exists. The new mass-spectrograph has been designed for such measurements and is now with Dr. Bainbridge in Cambridge.

The Collection of Isotopes in Large Amounts.—In the experiments of Dr. Bainbridge the actual amounts of isotopes falling on the photographic plates, are extremely small. The object in those experiments is the measurements of the masses of the isotopes. However, within the last two or three years, the possibilities concerned with transmutation of the elements by artifical means have increased very greatly; and with this development has gone the necessity of being able to utilize not only pure elements but pure isotopes of the elements in order

that one may be able properly to interpret the significance of the results produced. For this reason, Dr. Rumbaugh of this laboratory has devised an apparatus in which it should be possible to collect relatively large amounts of the pure isotopes, amounts comparable with a milligram, so that one may actually use the pure isotopes themselves in such disintegration experiments as those to which I have referred. It is easy to produce plenty of the charged ions of the isotopes within a sufficiently large volume and to give them energy by means of an electric field. The trouble is to separate out the different individual isotopes, and bring them into separate, relatively small areas. The general principle of Dr. Rumbaugh's apparatus will be clear from Fig. 7. The beam of ions of the isotopes of various kinds is caused to enter a magnetic field which, in Fig. 7, is perpendicular to the paper in

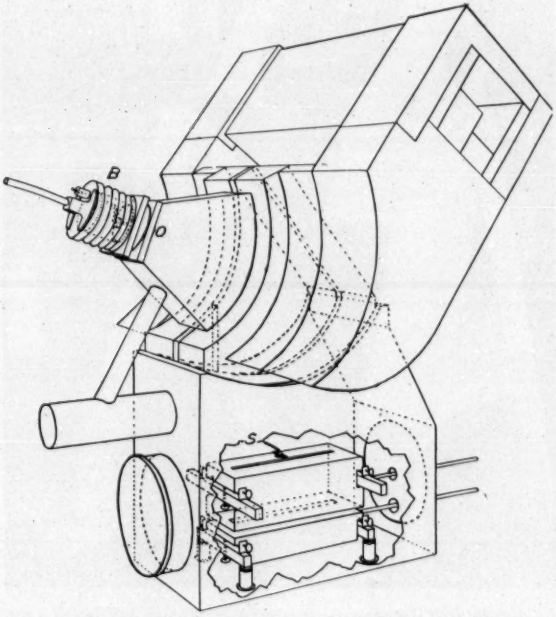
FIG. 7.



the shaded region. The paths of any particular isotope are now bent into arcs of circles, so that their directions are changed from parallelism in such a manner that those emerging from the field at the point A, do so in the direction AO, while those emerging at B continue their paths in the

direction *BO*. Thus all of the ions of one mass emerging from the field between *A* and *B* become concentrated to a focus at *O*. Ions of another mass are focussed at a different point. The design and construction of this apparatus has involved the most careful consideration of several points, chief among which are: (1) the proper design of the pole pieces *ACB*, and *PQR*, which determine the field paths in the shaded region, and (2) the arrangement of the conditions in that part of the apparatus in which velocity is imparted to the ions so as

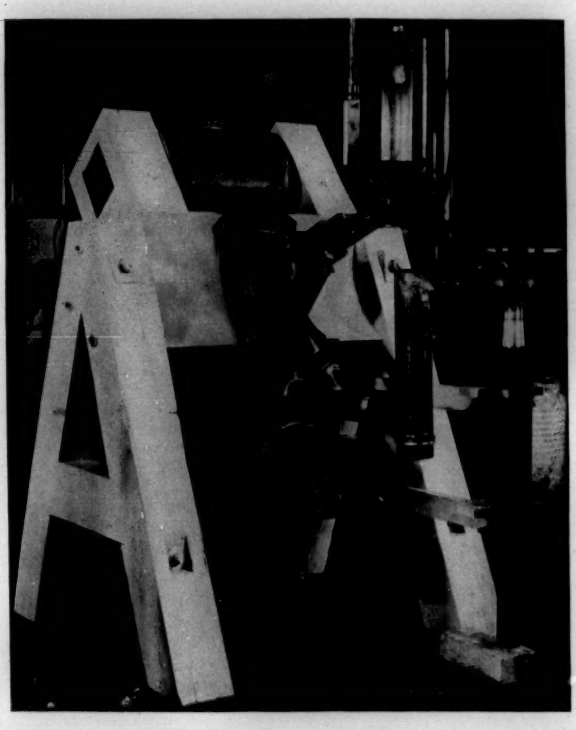
FIG. 8.



to secure in them a parallel beam of uniform velocity, (3) development of a suitable means of producing a beam of high intensity. Fig. 8, represents a perspective drawing of the

apparatus in which the lower part represents the apparatus for production of the ions which emerge through the slit *S*. The general shape of the pole pieces is indicated by *PQR*, and the focus spot is in the box at *O*. It is capable of adjustment

FIG. 9.



as regards its distance from the pole pieces by means of a flexible metal bellows, shown at *B*. Fig. 9, is an actual photograph of the apparatus. So far the experiences of the apparatus have been confined to being born and trained for its

life's work. It is just commencing the serious duty of segregating individual isotopes in amounts which we expect to be considerably greater than have ever been secured before.

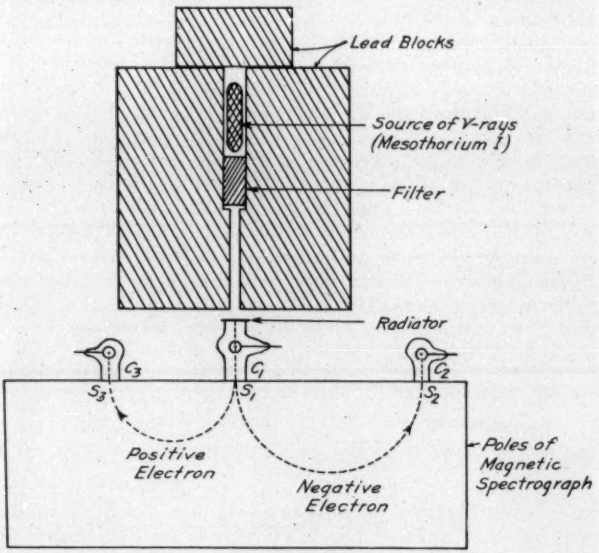
Further Investigations on the Mass-Energy Relation.—The energy whose mass equivalent was studied in the work of Bainbridge existed in the form of the kinetic energies of the alpha particles and of the protons. An even more significant application of the relation concerns the equivalence of mass and energy in the case where the energy is of the radiation form. If gamma rays of sufficient hardness are fired at a substance, positrons and electrons are ejected. A theory of the mechanism of the action, which is very agreeable to the modern school of thought, is one which postulates that the gamma ray, on experiencing a suitable encounter with the nucleus of an atom of the substance, suddenly suffers a transformation into two material particles, one the positron and the other an electron, so that it is intriguing to think of the emission of electrons and positrons in this experiment as representative of the real birth of matter from radiation, the radiation in this case being in the form of gamma rays. If this view is correct, and if the mass-energy relation is correct, it should follow that

$$\text{energy of gamma ray}/c^2 = \text{mass of positron} + \text{mass of electron} + (\text{energy of positron} + \text{energy of electron})/c^2. \quad (3)$$

Now, the energies of the gamma rays are known, in certain cases, from radioactive considerations into which I need not enter, so that when such is the case it is possible to test the foregoing views by measuring the energies of the electron and positron. An experiment for this purpose has been planned by Dr. G. L. Locher, who is carrying it out in conjunction with Mr. C. L. Haines. The principle is diagrammatically represented in Fig. 10. The gamma rays are obtained from mesothorium, the energy of these rays being known. They are allowed to fall upon the metal marked "radiator." The masses of material above represent shields whose purpose is subsidiary. The charged particles which are produced then travel in the downward direction and are subjected to the

influence of a magnetic field perpendicular to the plane of the paper. This magnetic field bends the paths of the positive and negative particles in opposite directions, into semicircles; and, by measurement of the diameters of the semicircles, it is possible to arrive at the energies of the particles, and so test

FIG. 10.



C_1, C_2, C_3 Geiger-Müller Counters
Simultaneous Discharges of C_1 and C_2, C_1 and C_3, C_1, C_2 and C_3 are Registered.

the mass-energy relation as represented by equation (3). The matter, however, is not quite as simple as it might seem at first sight. It is not sufficient simply to measure the deviations of the rays by their action on a photographic plate, because our theories and experience alike teach us that we must not expect that in the conversion of a gamma ray into an

electron and a positron we shall always find the same ratio between the energies of the positron and the electron. It is to some extent a matter of chance as to how much of the energy available from the photon shall go to each. For these reasons Dr. Locher and Mr. Haines use three Geiger-Mueller counters, as shown in Fig. 10. I have referred in former reports to the Geiger-Mueller counter, and shall speak of it again in due course in this report. For the moment it will suffice to regard it as a device for counting, by electrical means, charged particles which enter it through a small opening. The middle counter, C, which is provided with a slit through which the particles emerge, serves a subsidiary purpose which we will refer to presently. The fundamental counters are C_2 and C_3. If C_2 be fixed in position, the negative rays which operate it are determined as regards their energy, by its position. The energy of the negatives which are observed being determined, the energy of the positives associated with them is also determined if the mass-energy law is true. In other words, for every position of C_2 there is one, and only one position of C_3 for which we may realize the condition that C_2 and C_3 operate simultaneously. If C_2 and C_3 are arranged in relation to their recording circuit so that the counters will only record when these operate simultaneously, the mass-energy relation will determine one, and only one, position of C_3, as resulting in a record when the position of C_2 is fixed. The object of the experiment is then to find whether the relative positions of C_2 and C_3 are in accordance with what would be calculated from the mass-energy relation.

In order to eliminate chance coincidences between C_2 and C_3 arising from rays having no connection with the phenomena but which happen to pass through C_2 and C_3 sufficiently nearly in time to count as simultaneous, the third counter C_1 is added, and the circuit is arranged so that it will only record when C_1, C_2, and C_3 operate simultaneously. The counter C_1 then greatly reduces the effects of accidental coincidences.

Figure 11, shows an actual picture of the apparatus. A is the magnet, B is one of the counters, shown separated from the apparatus, and C is the electrical recording mechanism associated with the counters.

FIG. 11.

INVESTIGATIONS RELATING TO GEIGER-MUELLER COUNTERS.

Although I have referred to the Geiger-Mueller counter in these reports, it may be well again to remind you of the principle of its action since it plays such an important role in modern investigations. It consists primarily of a wire surrounded by a metal cylinder, the two being enclosed in a glass tube containing gas at low pressure. Between the wire and the cylinder there is maintained a potential difference which is just insufficient to break down the insulation of the gas. If an electron passes through this cylinder, or if an electron is liberated from the gas or the walls of the cylinder by an X-ray or a gamma ray from radium, the production of ions by the electron precipitates a discharge; and the current resulting

from this discharge may be made to operate a suitable amplifying device and to record itself in any manner desired.

Such counters have been used extensively for detecting the high speed electrons associated with cosmic rays. However, for such purposes a single counter is unsuitable because it responds to gamma rays from radioactive materials as well as to cosmic rays. If we have two such counters arranged in line it is possible to devise for them an amplifying system which will only record provided that both of them are discharged simultaneously. Such an arrangement will then not respond to gamma rays, because the chance that a gamma ray passing through will emit an electron in each is infinitesimal. The pair of counters will respond only to entities such as charged particles which produce ionization along the whole of their paths, and will respond only to particles of this type provided that their energies are sufficiently great to take them through the walls of both counters.

The reliability of the counter system is enhanced still further by having three such counters in line, arranged in such a manner in relation to a suitably designed amplifying system that they will only record if each of the three discharges simultaneously. This is the type of apparatus which has been used in much of the recent work on cosmic rays. It can obviously be used as a telescope to investigate variation of cosmic ray intensities with altitude and with azimuth.

Although a single counter is unsuitable for cosmic ray investigations, it is useful as a detector of X-rays, gamma rays, and ultraviolet light, etc. However, in such cases its use as a quantitative instrument is attended with difficulty because, of all the X-rays, for example, passing through the counter, only a few—about one in a hundred—liberate electrons and so discharge the counter. Thus, for quantitative measurements it is necessary to determine the efficiency of the counter. This is by no means an easy matter because we have no way of sending on to it a known number of X-rays to standardize it.

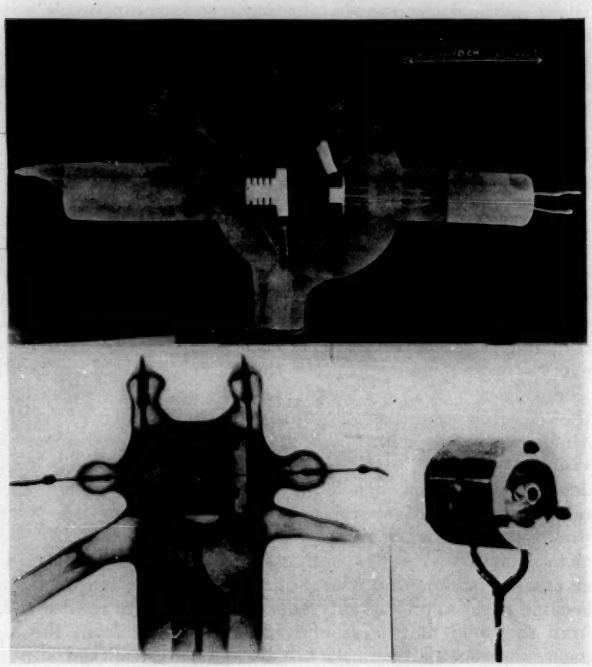
Determination of the Efficiency of a Counter for X-rays.—A method of standardizing a counter for X-rays and so of using it for quantitative measurements has recently been devised by Dr. G. L. Locher, and applied by Dr. Locher and Mr. LeGalley at the Bartol Foundation. Dr. Locher's scheme involves

filling the counter with krypton at a known pressure and arranging matters so that a beam of X-rays may be made to pass through holes in the metal cylinder of the counter, miss the central wire, and so encounter nothing but the gas. The holes themselves are covered with cellophane, so thin as to contribute no appreciable number of electrons as a result of the passage of the X-rays. The cylindrical ends of the counter are also closed with mica, so that the only electrons making their appearance in the active region of the counter are those actually produced in the gas in that region by the X-rays.

Now, from theoretical considerations we know the fraction of X-rays of any given wave-length, which will emit an electron in passing through a known length of gas at a known pressure. Using this factor, and assuming, as is perfectly well justified, that each electron liberated discharges the counter, Dr. Locher and Mr. LeGalley were able to determine the number of X-ray quanta emitted in a given time by an X-ray source of known wave-length. The source, having thus been standardized, may, of course, be used to standardize any other counter for the wave-length concerned. Fig. 12 shows a picture of the X-ray tube and of the counter used in these experiments.

Determination of the Sensitivity of X-Ray Film.—In an extension of the investigation, Dr. Locher and Mr. LeGalley have used the standard source to determine the sensitivity of a photographic film for X-rays of the wave-length concerned, and they have also determined the degree of absorbability of the X-rays in the film. I can perhaps summarize the results by quoting the following data from their paper, which is now in the process of publication. It is found that for X-rays from zirconium, which have a wave-length corresponding to 15,000 volts, three-quarters of a million quanta per square centimeter falling on the film produce observable blackening. This number of quanta corresponds to about 40,000 quanta actually absorbed in the emulsion. For the purpose of visualizing what this means it may be of interest to remark that in sunlight about a million million million quanta fall upon one square centimeter per second. The film used in the investigations to which I have referred was an Eastman Ultra-Speed Duplitized X-Ray Film.

FIG. 12.



a-tube. b-counter.

EXPERIMENTS CONCERNING COSMIC RAYS AND ALLIED PHENOMENA.

An important field of nuclear physics is that which has to do with cosmic rays. Even today there is some uncertainty as to the nature of these rays. According to the views of Millikan, they are, in part at any rate, composed of photons of such high energy that potential differences of the order of one thousand million to ten thousand million volts would be necessary for their creation. They are probably, in part at any rate, composed of charged particles of such an energy that

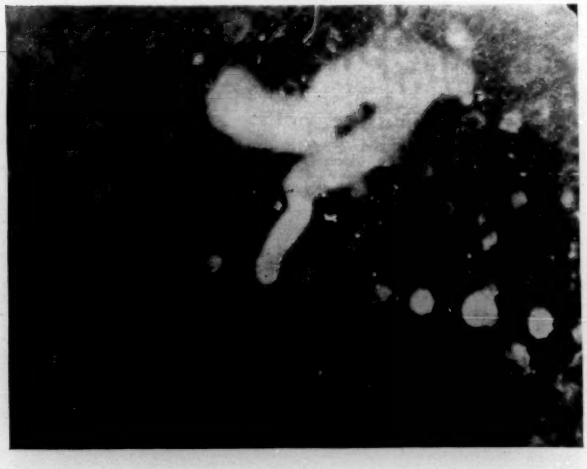
a voltage of this magnitude would be necessary to produce them. Whatever may be the nature of the primary rays entering our atmosphere, these primary rays certainly knock electrons and positrons out of the atoms of air which they encounter, or, at any rate, they cause such entities to make their appearance with energies greater than anything we can produce in the laboratory, and it is the characteristics of these high energy rays which form a large part of cosmic ray investigations.

Showers of Charged Particles in the Atmosphere.—Our first notions as to the state of affairs concerned with the secondary radiation in the atmosphere were founded on a view in which we might have, for example, primary photons entering the atmosphere at random, each one ejecting at some time or other a single charged particle from an atom, perhaps only once, if it communicated the whole of its energy in the act, or perhaps every now and again if it acted through what is known as the Compton effect. Then, in addition, we might have admitted the possibility of primary charged particles entering the atmosphere at random. The net result of this picture was a vision of charged particles flying about more or less in a downward direction with complete irregularity as regards any relationship with one another. In other words, the view would permit us always to find a time so small that the chance of two particles passing simultaneously through any given area in that time was infinitesimal. Soon, however, it became necessary to modify this picture, and to realize that from the solid matter around us, and indeed from the air itself, showers of particles are occasionally emitted simultaneously, presumably by the action of some primary radiation.

Experiments by Cloud Expansion Methods.—I will first speak of experiments concerned with the characteristics of these showers and involving the use of the cloud expansion chamber. It will be recalled that if dust-free moist air be suddenly expanded and so cooled, the ions produced by an ionizing agent passing through it will serve as centers of condensation for the water and so render the path of the ionizing agent visible. This method, which was first devised by Dr. C. T. R. Wilson for examining the paths of alpha

particles has been extended to the more difficult field of cosmic rays by Skobelzyn and by Locher and Mott-Smith. Fig. 13, which I showed in my report last year, is a magnified picture of a track obtained by Locher showing the individual drops. If the tracks are formed in a magnetic field the paths of the

FIG. 13.

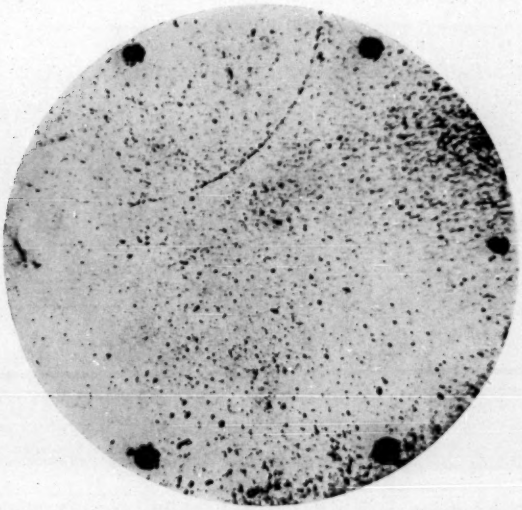


particles causing the ionization are bent into arcs of semicircles in virtue of the charges which they carry; and from the radii of these circles it is possible to determine the energies of the particles. Fig. 14, is a very beautiful track obtained by Anderson at the California Institute of Technology. As to whether the path is bent from left to right, or right to left, depends upon the sign of the charge, and of course the direction of the magnetic field. It will be recalled that this cloud expansion method, as it is called, has recently revealed, in the hands of Anderson, that long-sought, new entity in physics, the positive electron, or positron.

Now, Dr. Locher has been employing the cloud chamber

expansion method for the examination of the nature of the particles produced in the showers to which I have already referred. By photographing the showers produced from a mass of lead with two cameras directed at different angles, it is possible to make use of the facts of stereoscopic vision to

FIG. 14.

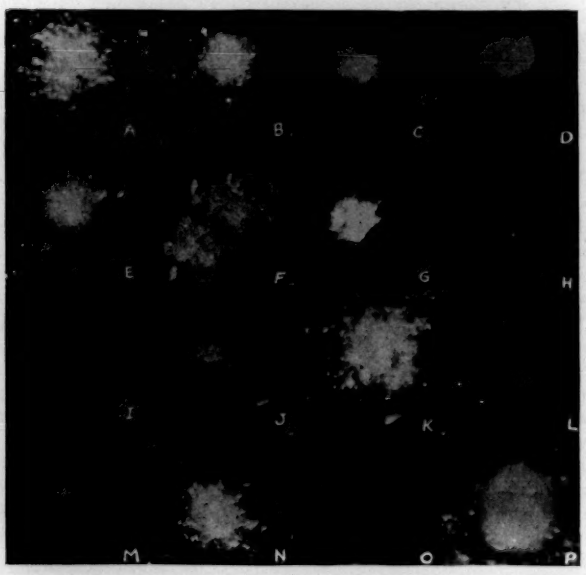


ascertain the points from which the showers radiate. Dr. Locher's experiments [6] have shown that they do not radiate from a common point. He is naturally keenly on the look-out to find whether in photographs of this kind several centers of rays originate on a straight line. Such a fact would strongly suggest the action of intermediate agents coming from a center of absorption of the original cosmic ray, and causing new centers of emission of showers of charged particles

[6] "Neutrons from Cosmic-Ray Stösse." *Phys. Rev.*, 44, No. 9, 779–781, November 1, 1933.

from atoms as they pass outwards. As a matter of fact, the existence of many centers of emission of the showers really *demands* the existence of intermediary agents; for a primary cosmic ray quantum cannot act at more than one point. It has been suggested by Dr. Locher that the intermediary agents are neutrons, and he has substantiated the suggestion by finding evidence of neutrons in the same photographs as

FIG. 15.

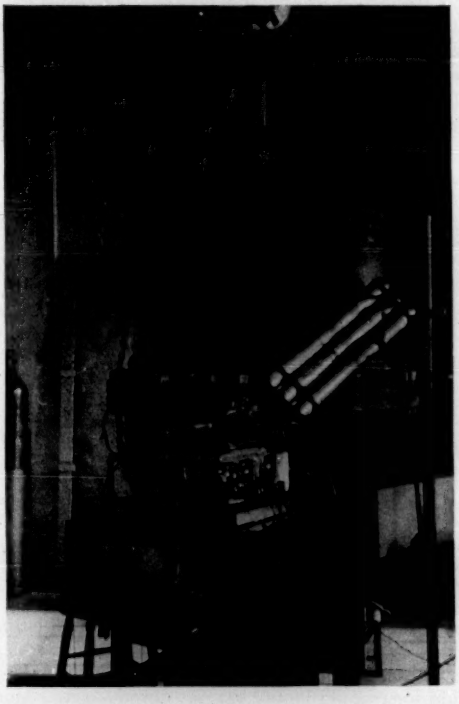


those which show the charged particle tracks. A neutron does not itself ionize directly but occasionally collides with an atom giving to it enough energy to enable it to ionize, which it then does very copiously on account of its heavy nature. In Fig. 15, from *K* to *P*, we have pictures of these ionization spots, or blobs, generated in argon by neutrons produced by

the bombardment of beryllium with alpha particles. Fig. 15, from *A* to *J*, shows the ionization blobs photographed by Dr. Locher in the same chamber as that which showed the charged particle tracks. The similarity with blobs produced by neutrons is unmistakable. The neutron is an entity with great penetrating power, and if it should be the intermediary agent operative in these phenomena, we can see how a cosmic ray quantum acting initially on an atom at one point might emit therefrom neutrons which would spread to relatively great distances in the material and initiate the disintegration of many atoms with the subsequent emission of positrons and electrons.

Experiments by Ionization Methods.—Fig. 16 shows a large iron vessel in which Dr. and Mrs. Montgomery and I have studied cosmic ray showers by the ionization which they produce. The general procedure has been to observe the showers in the top and bottom halves, separately, with and without thick slabs of lead, paraffin, or other material across the middle. When a shower of particles occurred it produced a spurt of ionization; and, by means of a potential difference between the vessel and two insulated electrodes associated with the top and bottom halves, these ions were swept across to the electrodes. The electrodes were connected to suitable amplifying systems associated with galvanometers which recorded photographically upon moving paper in such a manner that the spurts from the two halves showed themselves as displacements of two lines, as is indicated in Fig. 17. Spurts of this kind had been observed by others, particularly in Germany, and also by Dr. Street and myself in this laboratory. The magnitude of some of them was of such amount as naturally to leave in the minds of some who had not actually experimented with them, some doubt as to their real significance. For this reason, Dr. Montgomery and I placed around the vessel three sets of counters each having an area of 250 sq. cms. The three sets of counters were so arranged that they would only operate the final recording mechanism providing that they discharged simultaneously. The mechanism in question comprised a lamp which became illuminated by the discharge and recorded a shadow upon the moving photographic paper. One edge of that shadow corresponded

FIG. 16.

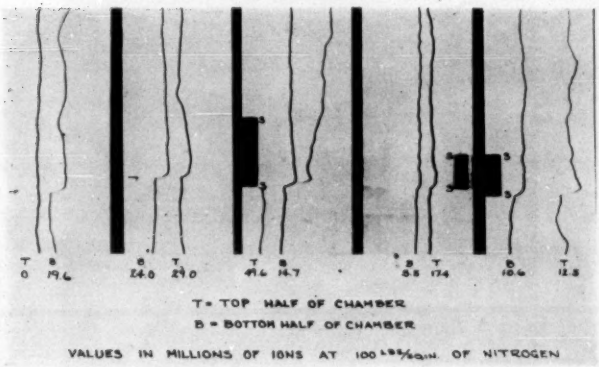


to the discharge of the counters, the other had no particular significance and depended simply upon the time which the light was left on. The thought was that if a burst of rays should emanate from some point in the wall of the vessel, for example, it would, in addition to causing a spurt of ionization, discharge the three sets of counters, so that the photographic trace would show the sudden displacement represented by that ionization; and, superposed upon that displacement, or in vertical line with it, would be the edge of the shadow indicating

the simultaneous discharge of the counters. The realization of such a situation was regarded by us as practically conclusive evidence of the existence of a shower of particles of such number as to succeed in sending at least one of them through each counter set, and of the production by these particles of the ionization observed in the photographic record.

At the time of my report last year I showed Fig. 18, which

FIG. 17.



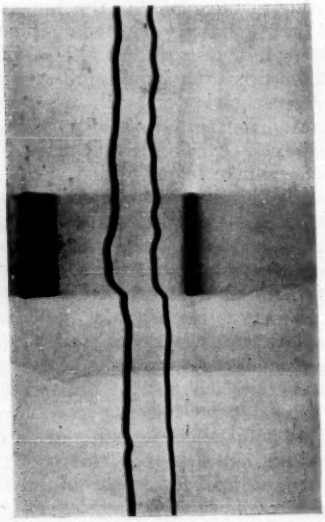
indicated a realization of the expected phenomena.[7] Since that time we have taken a number of additional photographs of this kind,[8] some of which are represented in Fig. 17. It will be observed that one of the spurts here recorded is so large that 50 million ions would be necessary to produce it. Moreover, to produce such a number of ions in the vessel would require about 1,200 rays of the electron type. In accordance with what might be expected, it was found that the largest bursts of ionization showed the greatest number of coincidences with the counter discharges; and, confining our attention to those

[7] "Non-Unidirectional Emission of Hoffmann Stösse." *Phys. Rev.*, 43, No. 9, 782, May 1, 1933.

[8] Cosmic Ray Nuclear Disintegrations. *Phys. Rev.*, 44, No. 1, 52–53, July 1, 1933.

bursts which produced more than 12 million ions, we find that 40 per cent. of them were accompanied by coincident counter discharges, a fact which requires us to assume that they contain on the average at least 250 rays. Such a number of rays would correspond to the production of about 10 million ions in the vessel. Thus both the counter data and the ionization data made with apparatus of an entirely different nature confirmed each other in assigning to these bursts

FIG. 18.



numbers of ions of the order of magnitude shown in Fig. 17, and numbers of rays of the order 1000, or more.

I may add that in one of the very many records taken a burst corresponding to as many as 5000 rays was observed.

An examination of Fig. 17, which is typical of the many observations, shows that in general the ion spurts are different in the top and bottom halves, and in some cases are absent in

one or the other half. This is only to be expected since the relative sizes of spurts in the two halves must depend upon the point of emission of the rays.

On placing across the center of the tank a slab of lead 7 cm. thick, it was found that the total number of spurts above the minimum size corresponding to four million ions produced in a fixed time, at a pressure of 100 lbs. per square inch, was increased by only about 12 per cent. although the amount of lead was comparable in volume with the volume of iron in the tank. The inference is that most of the spurts observed originated outside of the tank—in the walls of the room for example—and that probably only the largest spurts originated from the tank itself or its contents. This, of course, leaves open the likelihood that even the smaller bursts observed in the tank are representative of much larger numbers of rays emanating from a point in the wall or ceiling, many of the rays falling, however, outside the tank itself.

When the data taken with the slab of lead across the center of the vessel are compared with those with the vessel empty it is found that the relative numbers of spurts which occur in the upper and lower halves, and the numbers which occur simultaneously in both halves are altered in such a way as to be consistent with the view that the lead performs two functions; e.g., it acts as the origin of the bursts initiated by the external radiation, and it serves as an absorber of some of the rays from the bursts originating above the lead. The results, moreover, indicate that the bursts originating in the lead amount to about 2.5 bursts per cubic centimeter per hundred thousand hours which amounts to about one burst per cubic foot in three hours. As a matter of fact, the data indicate that 7 cms. of lead absorb half of the corpuscular rays in their passage through it. Our knowledge of the dependence of the absorbability of the rays upon their energy as derived from the experiments of Anderson would then lead us to believe that the rays from these bursts have energies corresponding to about 2×10^8, so that a thousand such rays would have energies such that a single electron would have to fall through 2×10^{11} volts to acquire that energy.

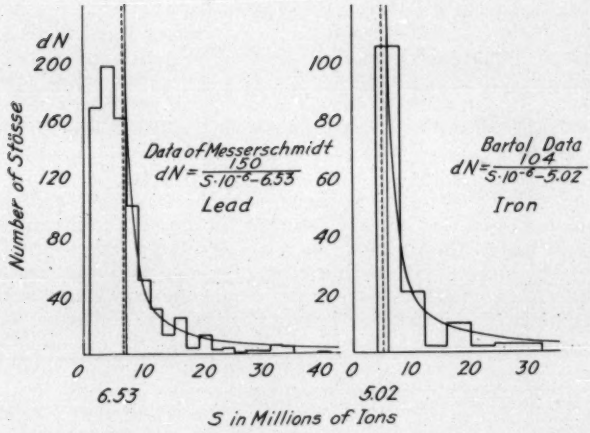
I have already referred to the cloud chamber experiments of Dr. Locher in which he found that these bursts emanate,

not from one point in the material, but from several points, a fact from which he drew the conclusion that the complete burst was to be accounted for by a primary burst, some of whose radiating entities possessed the power to initiate secondary bursts, and so on. Now the data concerned with the examination of the bursts in the upper and lower half of the tank in the case of an aluminum partition lead to the conclusion that the effect of the aluminum per unit volume is really less than that of the lead as regards initiating primary bursts, but that it does act as a means of enhancing the size of bursts originating above it, so that the bursts of ions in the lower half of the vessel are increased by its presence.

This question of the initiation of secondary bursts in the mass of the material is one of profound significance, and leads immediately to the conclusion that the size of a complete burst should depend upon the amount of material in which the burst originates, up at any rate to a size such as would involve the complete absorption of all of the rays involved in the primary burst and its successors. Dr. Montgomery [9] has worked out the details of what is to be expected in the way of distribution of the relative numbers of bursts of different sizes, based upon this idea of the existence of a primary burst which through successive actions builds up the complete shower of rays observed. Thus, for example, in a horizontal slab of material a primary burst occurring near the bottom will in successive perpetuations of itself through secondaries, etc., give rise to a shower which is relatively small on account of the fact that the initial act *did* occur near the bottom, so that there was not much material left to participate. On the other hand, a primary burst initiated far from the bottom will have much material below it for the purpose of enhancement of its size through secondary bursts from its successive offspring. When the whole matter is submitted to calculation, it is possible to construct a curve in which the ordinates represent the number of bursts contained between the size of burst indicated by the abscissa and that size plus unity, size being measured, for example, in number of ions. Such a theoretical curve is shown in Fig. 19, and upon it is superposed

[9] "A Possible Explanation of the Frequency Distribution of Sizes of Hoffmann Stösse." *Phys. Rev.*, **45**, No. 1, 62, January 1, 1934.

FIG. 19.

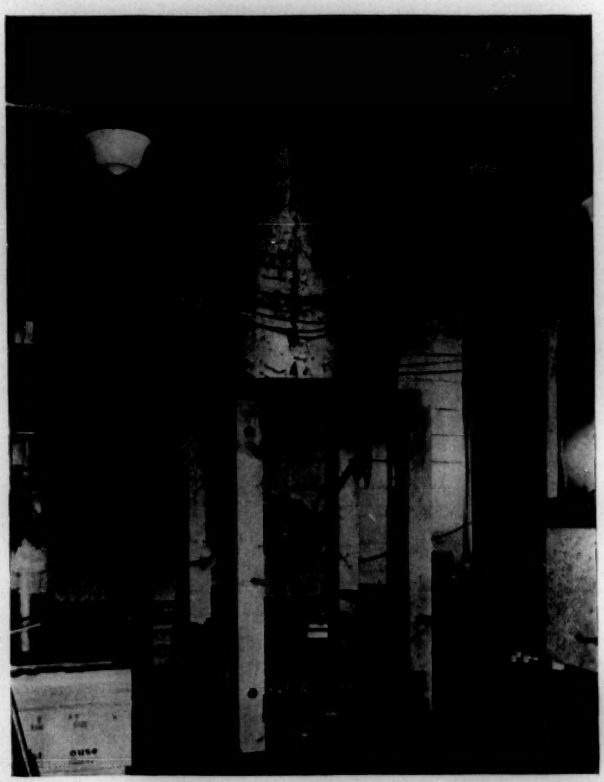


the experimental curve obtained from the data in the vessel.[10] In the adjustment of the experimental curve to fit the theoretical curve, two constants have to be appropriately assigned, one having to do with the difference in size between the primary and secondary bursts, and the other the distance over which one of the secondary particles travels before itself producing a burst. Although it is well-known to the physicist that much can be done in fitting an experimental to a theoretical curve when one has two arbitrary constants to play with, the significant thing about this particular theory is this; practically the only rival to the theory would be one in which one would suppose that the primary group produced secondaries all along its path and that the secondaries did not themselves produce tertiaries. It is easy to show that such a picture would give a curve fundamentally different from that shown in Fig. 19, whatever constants might be chosen in the process of attempting to adjust the theory to the facts.

[10] The heights of the rectangles on the experimental graphs represent the numbers of bursts obtained in a fixed time and lying between the sizes represented by the widths of the corresponding rectangles.

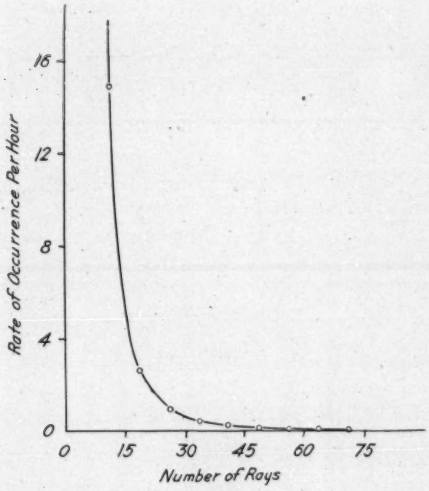
Having come to the conclusion that the production of secondary and tertiary Stösse forms a very significant part of the mechanism of the whole process, Dr. and Mrs. Montgomery and I planned an experiment in which the burst-producing potentialities were examined for the large tank shown in Fig. 20, which could be filled to any desired depth

FIG. 20.



with water. The vessel in which the ionization bursts were observed is the spherical vessel shown below the tank. This experiment is now in progress; but, while its main object is not yet fulfilled, it has given certain other information which is little concerned with the water or with the tank, but is concerned mainly with what happens as regards the nature of the ionization in a vessel when exposed to nothing but the room, and indeed, we wish now, to nothing but the free atmosphere. Fig. 21, represents a distribution graph for the

FIG. 21.



bursts of ions obtained in the small sphere. The ordinates of the curve give the numbers of bursts obtained with numbers of rays corresponding to the limit indicated by the abscissæ Now the significant fact which is to be extracted from this graph is to the effect that the small bursts, at any rate, are not to be regarded as rare phenomena. Moreover, as regards the total ionization in the sphere, this ionization is by no means to be thought of as produced almost entirely by tiny little

spurts, each one representative of a single charged particle passing through the vessel. There are all sorts of groups passing through the vessel. There are large very dense groups of rays, which from time to time pass through as a body. There are smaller groups, and there are groups of all sizes ranging down to single rays. The effect of a single ray would, however, be undetectable with our present apparatus which detects groups down to about five rays. The data show that the total ionization in the vessel is made up of 0.1 per cent. produced by groups of more than 100 rays passing through the vessel, 0.3 per cent. by groups of more than 50 rays, 1.6 per cent. by groups of more than 15 rays, and 3.9 per cent. by groups of more than 5 rays.

These results are in harmony with, and serve to extend, the conclusions reached in measurements which I reported last year on ionization by individual secondary cosmic rays, and in which it was found that in a vessel of dimensions 15 cms. long and 7.5 cms. in diameter, one-third of the spurts of ionization were produced by rays in groups of two or more, and two-thirds of the total ionization were produced by such groups. The existence of groups of this kind has, of course, been inferred from other considerations and in particular from the work of Dr. Street at our laboratory, to which work I have referred in last year's report. The present experiments, however, and those forming a by-product of the measurement of the ionization per centimeter of path form a direct realization of the existence of these spurts of multiple rays.

Naturally the existence of this state of affairs in the atmosphere has a profound significance in the interpretation of data given by double and triple counter sets, since three such rays passing independently through the three units of a triple coincidence set are guilty of masquerading as a single ray which has passed through all three. Effects of this kind have been independently inferred indirectly from counter measurements by Dr. Johnson and Dr. Street, and by the Montgomeries and myself.

I would conclude the account of these experiments on the production of showers by reference to another set of experiments which Dr. and Mrs. Montgomery have carried out and in which counters only have been used. Fig. 22, represents a

picture of the apparatus, with the five counters arranged in a star. The star was placed in a horizontal plane and above it was placed a disc of paraffin of equal total area and of thickness 7 cms. The counters could be used four at a time, or five at a time, and in either arrangement they were used in such a manner that the amplifier recorded only if all of those used discharged. Now only in the case of showers containing an

FIG. 22.

infinite number of rays would all of the counters be discharged on the occasion of each shower. If the number of rays from a shower is finite the number of occasions on which, in a given time, the five counters will discharge will be less than the number of occasions on which the four counters would discharge. In fact, the ratio of the number of discharges of the four counters to the number of discharges of the five is a quantity which is determined entirely by the average density of the electrons in the shower, as they strike the counters, so that this ratio serves to determine that density. The fact that the showers originate partly in the ceiling of the room at

any rate necessitates the performance of two sets of experiments, one with, and the other without, the paraffin. At present there is an ambiguity in interpretation of results which will necessitate further experiments to decide between two possibilities, of which, indeed, there may be a combination. The first of these is that, on the average, the paraffin emits 2 bursts per cubic meter per hour, with a density of rays which is greater than 150 rays per square meter at a distance of a meter from the paraffin. The second is that the paraffin acts to increase the size of primary showers originating in the ceiling to such an extent as to increase the number of rays passing through the area comprised by the counter (about 3500 sq. cms.) from 12 to 25.

The phenomena concerned with these bursts of particles initiated presumably by cosmic rays are complicated and involve several interacting agents. We are in somewhat the same position in regard to them that we were in with regard to radioactivity soon after Becquerel's discovery of the existence of that phenomenon. We may hope that with the progress of time the various relevant elements will become dissected out in such a manner that the story of all that happens and its relation to different kinds of matter may be told in a manner as clear-cut and unambiguous as the story of radioactive phenomena may be told today.

Ions Produced per Centimeter of Path by Secondary Cosmic Rays.—The simplest type of shower is, of course, one which is not a shower at all, but is simply a single charged particle passing through the measuring apparatus. A question of fundamental significance in relation to the behavior of such a charged particle is how many ions it produces in each centimeter of its path. Until comparatively recently the magnitude of this quantity had been inferred to a large extent from indirect evidence and there were discrepancies amounting to a factor of four between the various values quoted.

Last year I described some experiments in which Mr. Ramsey and I measured the spurts of ionization produced by individual cosmic rays in passing through a vertical cylinder 15 cms. high, and 7.5 cms. in diameter. We arrived tentatively at the conclusion that the number of ions produced per centimeter of path in oxygen, nitrogen and argon at atmos-

pheric pressure is 55, 60, and 89, respectively. The determination of these numbers involves the solution of a rather intricate problem of the relative numbers of rays of different path length in the cylinder as determined by the distances across it in various directions. Since my last report I have obtained the accurate mathematical solution of this problem;[11] and the net result has been to confirm the foregoing values.[12] We have also confirmed the tentative conclusions formerly arrived at to the effect that in addition to single rays passing through the cylinder there was a sufficient number of groups consisting of two or more rays to account for two-thirds of the total ionization observed. It must be remarked, however, that, in these experiments, the cylinder was surrounded by a casing of lead 7 cms. in thickness.

We are now continuing these experiments with an improved form of apparatus which should serve to give more accurate values for the ions per centimeter of path, and to free the results entirely from the influence of spurts of ionization caused by more than one ray. We are, in fact, making measurements of the ionization in conjunction with records given by cosmic ray counters, and in such a manner that only in those cases where the counters have given a guarantee that the spurt of ionization has been caused by a single ray, will we take cognizance of that spurt as representative of what we are seeking.

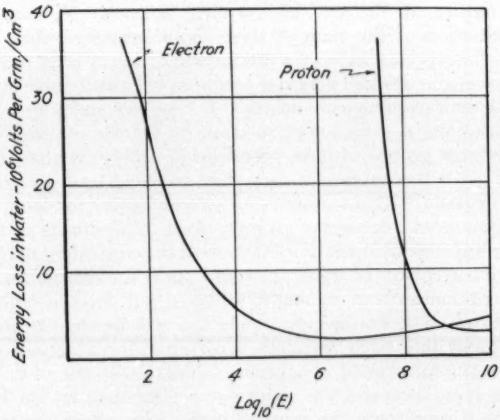
Our reason for wishing to extend the accuracy of these experiments is the following. Fig. 23, represents the way in which the energy loss per centimeter of path of an electron ray and so the ionization per centimeter of path by the ray depends upon its energy, E. The significant thing is that there is a minimum for energies of the order of a million volts. However, for rays of energy 10^8 volts the ionization per centimeter of path should be fifty per cent. greater, and, at 10^{10} volts, it should be one hundred per cent. greater. Now such energies lie within the range of those to be expected in cosmic ray observation so that it should be possible to verify the

[11] "The Distribution of Cosmic Ray Paths in a Vertical Cylinder," JOUR. OF FRANKLIN INST., 5, No. 5, 559–581, November, 1933.

[12] "Measurement of the Ionization per Centimeter of Path by Individual Secondary Cosmic Rays." *Phys. Rev.*, 44, No. 12, 961–968, December 15, 1933.

portion of the curve which shows a rise of absorption with increase of energy. Even our present data contain some information on this point. The importance of verifying this rise is that the rise itself is a prediction of, and so is characteristic of, features of the most modern forms of theories of atomic processes. Even the most refined forms of classical theories gave no reason to expect such a rise, but predicted

FIG. 23.



that the ionization-energy curve would fall gradually and asymptotically to a limiting value which is not very far different from the value corresponding to a million volts energy.

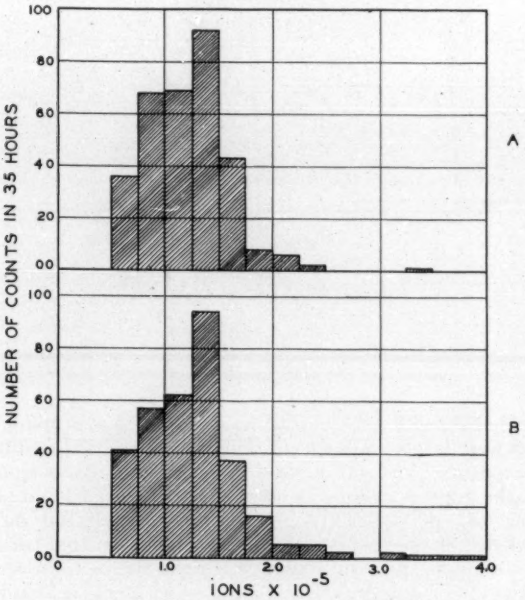
Investigations of Larger Spurts of Ions.—An examination of our experiments designed primarily to measure the ionization per centimeter of path shows that occasionally spurts were produced which were not readily attributable to as few as even fifty rays of the electron type, and there is some difficulty in supposing that as many as fifty rays of the shower type could pass through such a relatively small space as that comprised by the cylinder used. To investigate this matter further we took an even smaller cylinder and reduced the sensitivity of the

apparatus so that the former spurts of ionization produced by single rays, or even by groups of small numbers of rays, were relatively small, while the larger spurts which formerly had been so great as to fall off our photographic records were brought into evidence and formed the major subject of investigation. We were stimulated still further to look for these spurts of ionization by the discovery by Dr. Locher of the large blobs to which I have already referred as having made their appearance in his expansion chamber investigations on the nature of the entities forming showers. A tentative examination of the sizes of these blobs suggested that they might be representative of a production of a very large number of ions such as would give rise to spurts of considerable size in direct ionization measurements. Dr. Locher and I were able to formulate a satisfactory mechanism for the realization of these large groups of ions, founded upon the fact that, if, as Dr. Locher has supposed, they were initiated by the collision of a neutron with an atomic nucleus, the suddenness of that collision would cause the atom to shed its electrons so that, travelling now as a positive entity with the equivalent of many positive electron charges, it would form an extraordinarily efficient ionizer and so might well account for the blobs in question. The significance of Fig. 24, will be clear from the statement that each rectangle represents, for a period of 35 hours, the number of rays giving ionization spurts of magnitudes lying between the extremes represented by its base. Curve *B* represents the results for the case where about 200 lbs. of a mixture of paraffin and aluminum was placed above the apparatus, and Curve *A* represents the results without this material. For the case *B*, in particular, an appreciable number of spurts were obtained which would correspond to what would be produced by 100 electrons crossing the cylinder. It is true that spurts which are the equivalent of those producible by 20 or 30 electrons could be produced by alpha particles, but some of the spurts are larger than those obtainable from any known alpha particle. Undoubtedly, large portions of the curves in the vicinity of the higher ordinates *are* produced by alpha particles.

In a modification of the foregoing experiments we made observations of the spurts of ionization, and, simultaneously,

observations with three counters immediately above the cylinder and three counters immediately below. The counters were arranged so that they would only record provided the top three or bottom three discharged simultaneously. The simultaneous discharge of three counters meant that a shower of charged particles had occurred of sufficient density to send

FIG. 24.

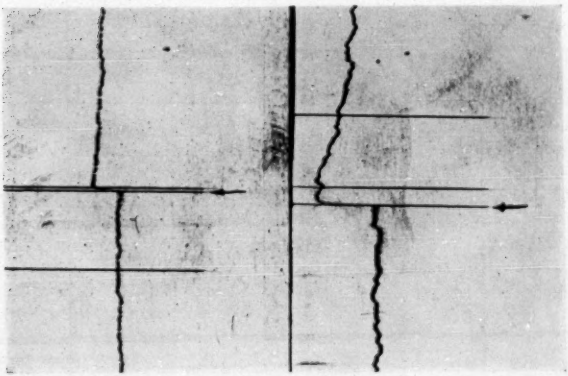


at least one particle through each of the three counters. The counters and the spurts produced by ionization in the cylinder recorded upon the same photographic trace. By confining our attention to those ionization spurts in the cylinder which were accompanied by a simultaneous record from the counters, it was insured that the ionization spurts thus observed were

those associated with the showers; for a consideration of the numbers of spurts involved showed that the chance that an alpha particle from radioactive contamination should produce a burst of ionization in the vessel simultaneously with the counter discharge was relatively small.

Figure 25 is a picture of the two spurts which showed

FIG. 25.

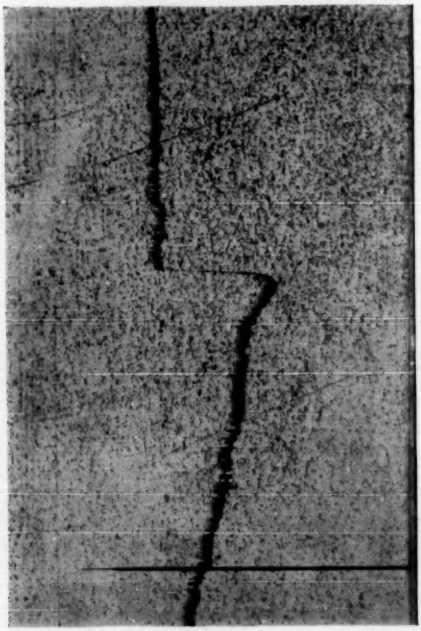


coincidences with the counter in a period of 120 hours, and which were larger than spurts which could be produced by an alpha particle. However, taking an alpha particle spurt as unit, the number of coincidence spurts between 0.2 and unity, during the period of 120 hours, was 22. Based on our knowledge of the number of alpha particles emitted per hour in the cylinder, and quite aside from the size of these spurts, the chance of any one of these coincidence spurts (having a size between 0.2 and unity) being produced by an alpha particle which showed an accidental coincidence with the counters is only one in five. Quite apart from the question of sizes, the chance of the large spurts in Fig. 25, being caused by alpha particles is infinitesimal.

If for the period of 120 hours we extend our interest to all of those spurts which were larger than the unit represented by an

alpha particle, regardless of whether or not they were associated with coincidences, we find 6 such spurts, of which the largest is represented in Fig. 26, and corresponds to 4 units in terms of the alpha particle. The excess of this number over the two showing coincidences cannot reasonably be attributed

FIG. 26.



to the fact that the counter sets were not 100 per cent. efficient for recording the showers, since each of the groups of three counters had an independent opportunity to record the showers. We are urged to the conclusion that some of these large spurts are unassociated with showers, or at most are associated with showers, the density of whose rays, in the

neighborhood of the ionization chamber, is too small to operate the counter sets. One is naturally tempted to think of charged atomic nuclei or charged atoms of energy, and probably mass, greater than that of alpha particles as responsible for these larger spurts of ionization; and it is a significant fact that some of Dr. Locher's cloud expansion photographs have shown the existence of such charged atoms or nuclei of high energy. The complete story of these matters must await further experiments. We have not yet decided as to whether in the totality of these large spurts of ionization enough exist of sufficiently large size to be the representative of those large blobs of apparent ionization to which I have referred in connection with Dr. Locher's experiments and which he attributed to results following from the impact of neutrons with the atoms of gas in the expansion chamber.

DEVIATION OF COSMIC RAY PATHS BY MAGNETIC FIELDS.

When a charged particle travels in a magnetic field, and in particular when it travels in a plane perpendicular to the lines of force of the field, it describes a path which is the arc of a circle. To fix our ideas as regards magnitude, we may say that a charged particle with an energy such as it would receive in a fall through a thousand million volts would describe a circle of radius 10^7 cms. in the magnetic field of the earth, and in such a magnetic field as is produced by a large electromagnet, the radius of curvature would be about 200 cms. It will readily be inferred that it is by no means easy to detect the bending of path produced by such a ray; for it is difficult to construct an apparatus which will give a magnetic field over a region of sufficiently large size to result in more than a small bending in the path of the particles, in that path length.

Deviation of Cosmic Rays in Magnetized Iron.—However, secondary cosmic rays can pass through considerable thicknesses of such material as iron. It has even been suggested that they can pass through a meter of lead, although there is some question as to whether an individual particle can pass through this thickness of material without, as it were, being born again. It is certain that such secondary cosmic rays as occur in nature can pass through 15 or 20 cms. of iron. Now our classical theories tell us that in passing through magnetized

iron, the path of a charged particle becomes deviated by two contributions to the magnetic force: (1) a contribution which, speaking rather crudely, we may say would be the force active in the absence of the ion; and (2) the force arising from the little molecular magnets which constitute the magnetized iron. The part of the magnetic force associated with the former of these contributions is usually denoted by H, and the part associated with the latter by I, the sum of the two being called B. Now in iron it is possible to obtain over large volumes values of B which are very much greater than the values which it is possible to obtain for H in the free air, or anywhere else for that matter. In fact it is quite readily possible to obtain, in a reasonably large volume, a value of B which would bend the path of a thousand million volt electron into the arc of a circle of radius 200 cms. Under these conditions it does not seem out of the realm of possibility to detect the variation of the path from straightness in a distance of, let us say, 15 cms., which is the distance in which it is quite possible to realize the value of B which I have cited.

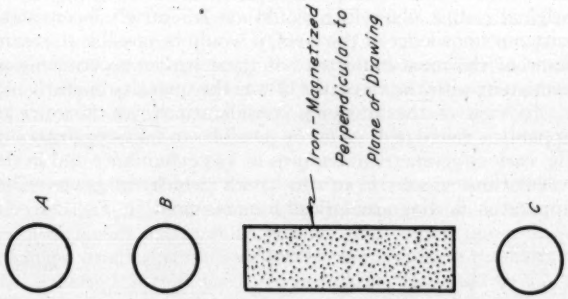
Experiments on the deviation of cosmic ray paths in magnetized iron have been carried out by former investigators who have concluded, as a result of them, that the rays are not bent anything like as much as they would be bent if the magnetic influence B were operative. It has in fact been inferred that the molecular magnets of the iron have no influence upon the rays. This matter is one of profound significance, not only as regards cosmic rays, but also as regards the fundamental nature of that entity which really provides for the magnetism of the individual molecules. The detailed theory of the subject shows that an electron in passing through a piece of magnetized iron experiences forces of a very erratic and varied kind which only produce an effect having significance when averaged over a large path distance. Speaking rather crudely, we may say that if the molecular magnets were extremely small in size then the experience of an electron in passing through a piece of magnetized iron would be this: It would pass for a relatively long distance without actually shooting *through* one of the magnetic entities. In this distance it would experience a relatively small magnetic deviation determined by what I have called H. Then, very

occasionally, it could pass right through one of the little magnets. This little magnet would proceed to make up for its lack of representation over most of the electron's path by giving the electron a very large deviation. In order that the net effect on the electron over the whole of its path should be represented by B, rather than by H, it is necessary for that path to be so long that over its length the electron experiences many times, that rare phenomenon of travelling right through the molecular magnet. Such a long path, however, would result in a very large total deviation, even if it could be travelled in the iron, and even if we should take a shorter path so that only once did an electron experience a passage through a molecular magnet in that path, that deviation might be so great as to shoot the electron completely to one side, and hurl it out of the category of those electrons which were observed by the experimenter. In such a case, the only electrons which the experimenter would observe would be those which had not had this experience. In other words, he would observe only those electrons which had suffered a deviation determined by H and which would have to travel very much farther in the iron in order that they should accumulate enough deflection in passing through the molecular magnets to average the deflection up to the value determined by B. The larger the size of the magnetic entity the less drastic the considerations to which I have referred. If the magnetic entity is so large that it extends effectively all over the atom, then we should expect that in any reasonable path distance the electron would experience a deviation determined by B rather than H. We see, therefore, how experiments on the deviation of electron paths in iron strike at the very heart of one of the most fundamental matters in atomic physics, the ultimate nature of the magnetic entity. There are many other experiments in which B plays its part as distinct from H, as for example the very simple experiment of the generation of the electromotive force in a coil as the result of magnetizing a piece of iron thrust through it. Here, however, the size of the magnetic entity plays no significant role, and the effects are the same whether it is small or large. Only by some such experiments as the passage of electrons through the iron can we send a spy right into the heart of the atom to ascertain what is going on

there. It is for these reasons that Dr. Danforth and I have taken up again this question of the deviation of cosmic rays in magnetized iron.

The general nature of the experiment, which has taken slightly different forms at different times, is such that we have three counters, *A*, *B* and *C* in line, with a piece of iron between *B* and *C*, Fig. 27. We count the number of cosmic rays which

FIG. 27.



pass in a given time through all the counters. Then we magnetize the iron in a direction perpendicular to the line of the counters, and make measurements again. We may interest ourselves either in the change of the number of counts under these conditions, or we may move the lower counter to various positions with the magnetic field on and off, and from a knowledge of the change in distribution of the counts, with the magnetic field on and off, we may attempt to deduce the effect of the magnetic field.

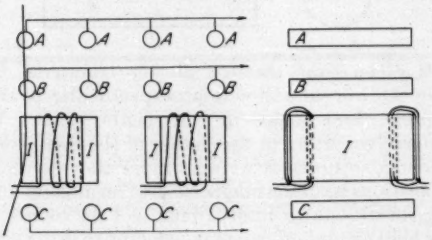
Now, in the first place, Dr. Danforth has made a careful analysis [13] of all of the geometrical elements which enter into the story of just what should happen, taking into account the fact that we cannot choose our cosmic rays at will, but have to accept what is given us, an assortment of all sorts of different cosmic ray energies superposed. He has also investigated the

[13] "Analysis of Cosmic Ray Deflection Experiments." JOUR. OF FRANKLIN INST., **217**, No. 3, 331–345, March, 1934.

effect of the iron in reducing the energy of the rays as they pass through it and so of modifying the deviation otherwise to be expected. The various details of this analysis, which have been published, are too complicated to take up at this time. It will suffice to say that the net conclusion is to the effect that the interpretation of former experiments cannot be regarded as conclusive evidence for or against the assumption that B is the quantity operative. In fact, Dr. Danforth was able to show that by the assumption of an energy distribution in the original cosmic rays which would not be entirely inconsistent with our knowledge of the facts, it would be possible to regard some of the most important of these earlier experiments as consistent with the view that B was the quantity operative.

In view of the foregoing considerations, we designed an apparatus calculated, as far as possible, to take cognizance of the various geometrical features in its performance and in the calculations made from the data which it gave. This apparatus is diagrammatically represented in Fig. 28. In

FIG. 28.



order to secure a large enough number of counts, and so diminish the time of the experiment, what amount to four independent systems were used, each having its three counters, A, B, C, and its piece of iron I. I need not refer in detail to the electrical windings necessary to secure the magnetic fields. It will suffice to say that the length of the iron was 15 cms., its width was 1.6 cms., the length of the counters was 20 cms,. and the magnetic induction B secured was 15,000 gauss. In view of the fact that the cosmic rays come in at random, it is

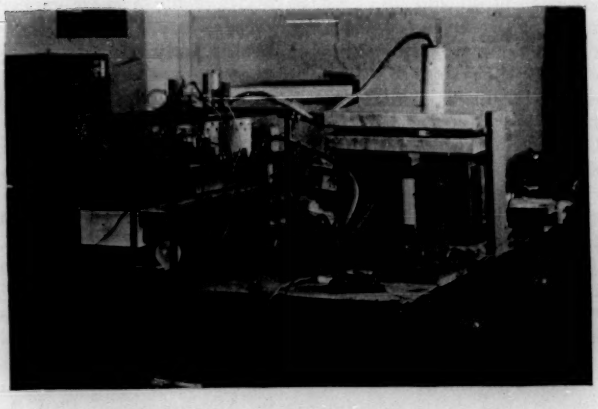
necessary to continue the experiment sufficiently long to iron out uncertainties resulting from this randomness. To secure an accuracy of 1 per cent., ten thousand counts are necessary, in any individual set of operations, and a thousand counts will give an average error of 3 per cent. Adding together the counts from the four independent systems gave about one count per minute. The experiments were continued for two weeks with, and two weeks without, the magnetic field, although, of course, these total times were staggered, so that observations were taken for short periods with the fields alternately on and off. As the result of all of these experiments, and assuming energy distribution curves obtained from cloud chamber experiments of Anderson and Kunze, it turned out that the results could be explained by the assumption that the vector operative was equal to about $B/5$, which is about 20 times H. By moving the top counter upwards and the bottom one downwards the apparatus becomes more sensitive to the smaller deviations and so becomes governed more by rays of higher energy. In another experiment under these changed conditions the results were explicable on the basis of the assumption that the force operative was equal to $2B/5$. The discrepancy between these two results may be due, in part, to the incompleteness of our knowledge of the distribution of the energy among the rays, particularly as this distribution is likely to depend upon the immediately local conditions, the nature of the walls of the room, and of other massive material in the vicinity. Incidentally, I may mention that in some recent experiments by Alvarez, one of Prof. A. H. Compton's students, which experiments were published at the same time as our own, the deviation of beta particles was measured in passing through thin films of magnetized iron. Here again the question between B and H becomes involved, and it is significant that the results of those experiments are explicable on the assumption that the quantity operable is not the whole value of B, but an appreciable fraction thereof. The present experiments on the deviation of the cosmic rays in iron are being continued in the hope that we may dissect from them as much information as possible concerning the details of the action of the molecular magnets which constitute the iron. The matter has a special interest at the present time

because the most modern theory of magnetism would, according to the usual interpretations, suggest that the magnetic entity covers an area comparable with the whole atom itself in which case the full value of B should be operative.

Figure 29 represents a picture of the apparatus actually used in this investigation.

Paths of Cosmic Ray Particles in the Earth's Magnetic Field.

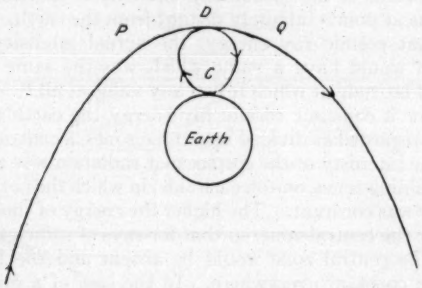
FIG. 29.



—Until a few years ago it was supposed that charged particles could play very little rôle as representatives of the primary cosmic radiation, since it was believed that the orbits of such particles would be bent by the earth's magnetic field in such a manner as to cause considerable variation in cosmic ray intensity with latitude. In spite of the smallness of the earth's magnetic field, its extension over great distances causes it to play a very potent part in bending the paths of charged particles. Thus, as I pointed out many years ago, an electron with a thousand million volts energy incident within the equatorial plane of the earth would not be able to approach nearer than eight times the earth's radius without being turned

back into space. An electron would have to have 10^{10} volts velocity to reach the earth at the equator if projected toward the earth in the equatorial plane. The orbits of electrons in the earth's magnetic field were discussed many years ago by Störmer, who showed that they were of quite a complicated nature, some of them showing loops and twists of various kinds. By a specially simple calculation as applied to an orbit in the equatorial plane I showed,[14] about two years ago, that the particular orbit which coming in the equatorial plane reached the earth with minimum energy was one which made a loop such as is indicated qualitatively in Fig. 30. The point

FIG. 30.



D of the loop is at a distance from the earth's surface equal to 1.5 times the earth's radius, and the energy of the particle which just succeeds in grazing the earth's surface is, as I have remarked, approximately 10^{10} volts. Thus in general we have to be very careful about associating the direction of electrons which would enter the earth's atmosphere with the directions of the paths which those electrons had at infinity.

Within the last year or two the experiments by Clay, in Europe, and A. H. Compton, in this country, in a world survey, have shown a definite variation with latitude amounting to about 14 per cent. at sea level between such latitudes as ours and that of the equator. There is very little variation

[14] "An Electron Orbit in the Magnetic Equatorial Plane of the Earth." JOUR. OF FRANKLIN INST., **214**, No. 4, 465–471, October, 1932.

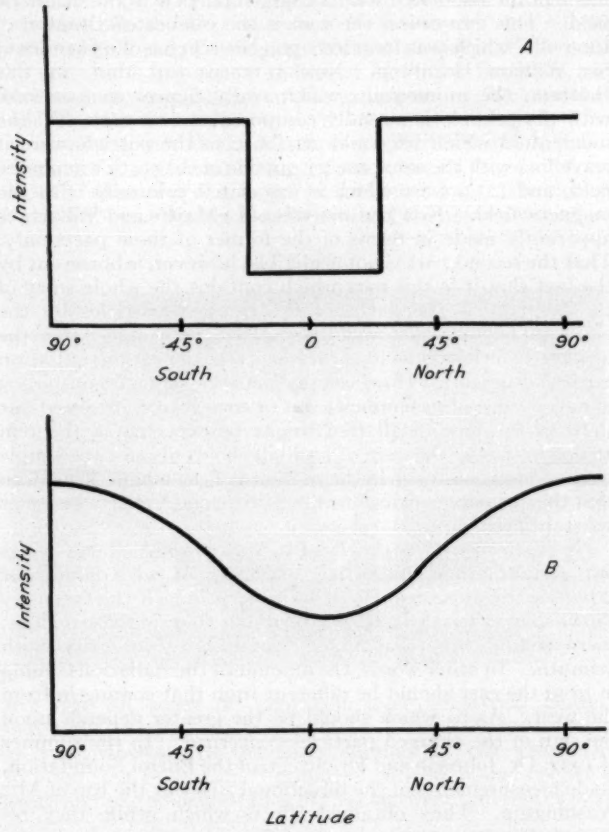
for higher latitudes, and this is probably the reason why the phenomenon was not observed before. The existence of an appreciable amount of the cosmic radiation in the form of charged corpuscular radiation was thus established with reasonable definiteness; but, in view of the complexity of the theoretical paths of the corpuscles the practical constancy of the intensity at higher latitudes was very surprising. Then came a paper by LeMaître and Vallarta in which they showed that nature did in this case what she has done in so many other cases. She has evolved out of a system of great complexity certain elements of extreme simplicity. LeMaître and Vallarta showed that in spite of the complexity in shape of the various orbits, if the cosmic ray intensity is the same in all directions at points infinitely distant from the earth, then, for a constant cosmic ray energy, the actual intensity of the radiation would have a value which was the same over all ranges of latitude at which it had any value at all.[15] In other words, for a constant cosmic ray energy the earth's surface could be regarded as divided into three zones, a central zone in which the intenisty of the corpuscular radiation was zero, and two remaining zones, one on each side, in which the corpuscular intensity was constant. The higher the energy of the rays the narrower the central zone, so that for rays of sufficiently high energy the central zone would be absent and the intensity would be constant everywhere. In the case of a mixture of energies we should have to combine a number of situations such as are represented in Fig. 31, *A*, but with central zones of different width, ranging down to and including zero width, so that the net result for the intensity distribution would be some such curve as is represented in Fig. 31, *B*. If we superpose upon this some additional radiations which are of non-corpuscular nature the effect will be to raise the whole curve from the horizontal axis.

I may here refer to a subsidiary theoretical investigation which I have carried out with this matter.[16] The whole of the

[15] A slight reservation must be made in the matter of variation of intensity with azimuth, to be referred to presently. This reservation concerns appreciably only the region of transition between finite and zero values of the intensity, however.

[16] "Application of Liouville's Theorem to Electron Orbits in the Earth's Magnetic Field." *Phys. Rev.*, **44**, No. 11, 224-227, June 1, 1933.

FIG. 31.

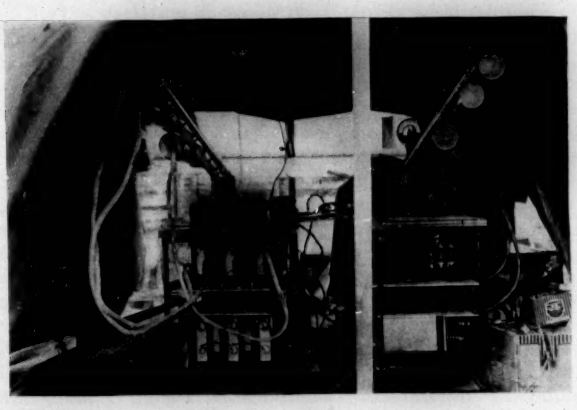

A
Intensity
90°
45°
0
45°
90°
South
North
B
Intensity
90°
45°
0
45°
90°
South
North
Latitude

simplicity brought out by the LeMaître-Vallarta theory depends upon a certain dynamical theorem involving the momentum associated with a charged particle in the magnetic field. This dynamical theorem is the celebrated theorem of Liouville, which was founded upon the scheme of dynamics of Sir William Hamilton. Now it turns out that, in this theorem, the momentum which really figures as *associated* with the particle is actually composed of two parts, (1) the momentum which we could attribute to the particle were it travelling with the same energy outside of the earth's magnetic field, and (2) a part which is associated primarily with the magnetic field. Now the analysis of LeMaître and Vallarta is apparently made in terms of the former of these parts only. That the second part is not negligible, however, is borne out by the fact that it is this part which contains the whole story of the bending of the paths of the charged particles by the magnetic field. There was thus a very great danger that the ultimate conclusion as to the intensity of the cosmic radiation might be invalid. However, by another strange conspiracy of nature to evolve simplicity out of complexity, it turned out that, in the face of all that might be expected, a theorem analogous to the theorem of Liouville holds also for the simple particle momenta even in the presence of the magnetic field, so that the ultimate conclusion of LeMaître and Vallarta becomes substantiated.

Now, the complete theory of LeMaître and Vallarta brings out certain other interesting features. If we confine our attention to those regions of latitude in which the intensity shows sharp variations, then it turns out that, in these regions, there should be a calculable variation of intensity with azimuth. In other words, the amount of the radiation coming in from the east should be different from that coming in from the west. As to which should be the greater depends upon the sign of the charged particles concerned. In the summer of 1932, Dr. Johnson and Dr. Street, of the Bartol Foundation, made measurements of the directional effect at the top of Mt. Washington. They obtained effects which, while they regarded them as tentative, were of the order of magnitude of 3 per cent., and of such a nature as to indicate positively charged particles as responsible, at any rate in part, for the corpuscular

radiation. In the spring of 1933, Dr. Johnson made a series of measurements in Mexico City,[17] since at the latitude of this region the experiments of Compton and his collaborators had indicated the sharpest variation with latitude, and so the greatest likelihood of obtaining substantially large effects. At the same time experiments planned by A. H. Compton and Alvarez were carried out at the same place. The results of Johnson and of Compton and Alvarez confirmed each other in showing a very decided east-west difference which varied with angular altitude, and was of the order of 10 per cent. for angles of the order of 45°–55° from the vertical. The nature of the difference was such as to demand the assumption of, at

FIG. 32.



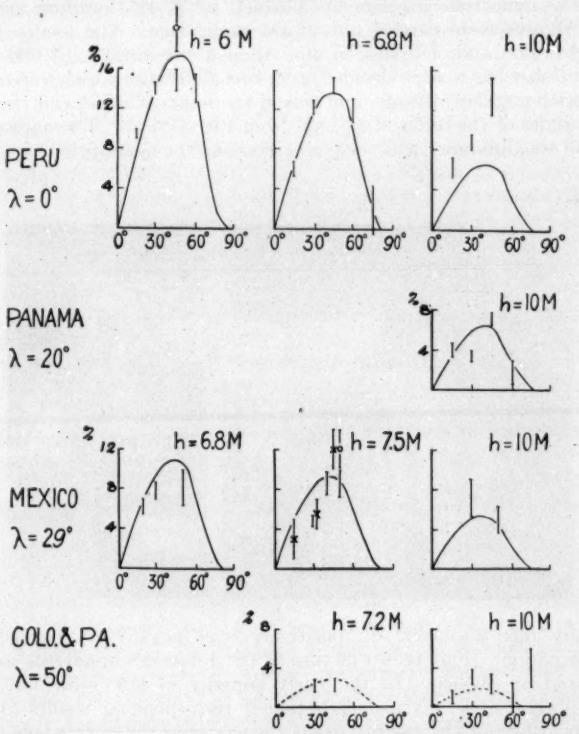
any rate an *excess* of, positively over negatively charged radiation. Fig. 32 is a picture of Dr. Johnson's apparatus as used in Mexico. In the early summer of last year, Drs. Johnson and Stevenson[18] obtained corresponding results at Swarthmore, the magnitudes of the east-west differences being

[17] "The Azimuthal Asymmetry of the Cosmic Radiation." *Phys. Rev.*, **43**, No. 10, 1–2, May 15, 1933.

[18] "The Asymmetry of the Cosmic Radiation at Swarthmore." *Phys. Rev.*, **44**, No. 2, 125–126, July 15, 1933.

smaller, however, as they should be on account of the higher latitude. Confirmatory results were also obtained by Dr. Stevenson in Colorado.[19] In the summer of last year, Dr. Johnson continued his investigations in more nearly equatorial

FIG. 33.



latitudes, in Panama and in Peru. His results are best summarized by an appeal to Fig. 33, in which the ordinates

[19] "Azimuthal Asymmetry of the Cosmic Radiation in Colorado." *Phys. Rev.*, 44, No. 10, 855, November 15, 1933.

represent the percentage excess of the west intensity over the east plotted against the angular distance from the zenith for different latitudes and altitudes. The curves themselves are drawn from LeMaître and Vallarta's theory and are adjusted as regards their constants so as to fit the observations at two points. The experimental data correspond to the centers of the short vertical lines and the lengths of those vertical lines represent the experimental uncertainties. h represents the effective distance below the top of the atmosphere in equivalent meters of water. The shapes of the curves vary with the altitude on account of the absorption of the rays by the atmosphere. Time will not permit me to analyze the results in detail. It must suffice to say that the significant conclusions to be drawn are the following:

1. The variation of cosmic ray intensity with latitude is of the same general nature for positive rays as for negative. If half of the rays were positive and half negative, this effect would not be obscured. The asymmetry effect, however, depends upon the existence of a difference between the positive and the negative intensities. It is possible to calculate from the experimental results of the asymmetry experiments what effect is to be expected in the intensity variations with latitude, only provided that one makes some assumption as to the ratio of the positive to the negative intensity. Dr. Johnson finds that the facts of the two types of experiment are harmonized within the limits of accuracy of the experiments by the assumption that the radiation is entirely positive, and he concludes that an assumption that more than 17 per cent. of it is negative would render the two types of experiment out of harmony with each other. Table I shows for different cases, in column 3, the percentage excess of the intensity of cosmic radiation over that at the equator, as calculated from the asymmetry data on the assumption that the charged particles are all positive. Columns 4, 5 and 6 give the corresponding magnitude of this quantity as experimentally measured by the observer cited at the heads of the columns. It will be seen that on the whole the results calculated from the asymmetry data agree with the measurements of different observers to within the limits of consistency of the measurements by those observers.

TABLE I.

Comparison of Observed Latitude Intensity Variation with Values Calculated from Asymmetry, Assuming an Exclusively Positive Corpuscular Component, Expressed as Per Cent. Increases Over the Value at the Equator.

Latitude.	Depth Meters of Water.	Percentage Difference from Value at Equator.				
		Calculated from Asymmetry.	Observed.			
			Compton.	Bowen, Millikan and Neher.	Clay.	Hoerlin.
20°	10	1	1	0	2	0
	6	3	3	0	—	—
29°	10	3	4		6	2
	6	7	10	—	—	—
50°	10	9	14	7		10
	6	23	33	25		

2. I have already referred to the existence in the atmosphere of showers of charged particles presumably generated therein by the action of some primary radiation coming from the outside and suffering collision with the atoms of the atmosphere. By methods analogous to those which I have already described, it is possible to measure the intensity and frequency of these showers produced in any substance; and, by suitable variations in the experiments, it is also possible to dissect out the absorption coefficient of the primary rays responsible for the showers. By placing absorbing material in the paths of the rays entering the counters in the directional experiments it is possible to determine the absorption coefficient of the rays responsible for that directional effect. Dr. Johnson has carried out experiments of this kind, and has found that the absorption coefficient of the rays which produce these showers is the same as that of the rays responsible for the directional effect. It is natural to conclude, therefore, that the shower-producing rays and the rays responsible for the directional effect are identical. This conclusion is in harmony with certain inferences to which I was driven soon after the discovery by Clay and Compton of the latitude effect. These inferences have been published in detail,[20] and I can only refer briefly to them. The situation is this:

[20] "On the Nature of the Primary Cosmic Radiation." *Phys. Rev.*, **43**, No. 11, June 1, 1933.

Latitude and directional effects necessitate the assumption of the existence of rays of charged particles comparable in energy with that which would be received under a potential difference of 10^{10} volts. Such rays should have no difficulty in passing right through our atmosphere if the whole of their energy were lost merely by the process of ordinary ionization. On the other hand, the cloud chamber experiments of Anderson to which again I have referred have given no evidence of existence of rays of this energy at any rate in amount such as would be necessary to explain the numerical values for the counter data were we to suppose that each count figuring in the east-west difference was the representative of one of these rays. It seemed, therefore, necessary to assume that these rays were non-ionizing in character. This would explain their failure to record themselves as high energy rays in the magnetic deviation experiments in the cloud chamber. It was necessary to suppose, however, that while these rays were non-ionizing in the sense that they failed to produce evenly spaced ions at the rate of about 30 per centimeter of path, they nevertheless ejected occasionally from the nuclei of the atoms by which they passed showers of rays which continued the direction of their flight. Such rays being of lower energy would ionize so that they would operate counters. Having handed on to them the directional properties of the primaries they would cause the counter experiment to reveal those directional effects. Even in the cloud chamber they would reveal themselves, but having a lower energy than the primaries they would show, of course, deviations in the magnetic field determinable from the energies which they actually possessed.

Many years ago, as I have remarked in former reports, I had occasion to seek some theoretical mechanism by which it might be possible to conclude that a charged particle of sufficiently high energy would fail to ionize. In terms of the classical theories of electrodynamics it was found possible satisfactorily to realize such a theoretical possibility. With the advent of the wave mechanics I sought some means by which such a situation could be evolved out of that form of theory also. It was found possible to introduce in a natural way an extension of the wave mechanical principles to permit

of such a possibility, and recently this extension has been put out and published in detailed form.[21] At my request Dr. Bramley has applied the modified wave mechanical theory to the problem of ionization so as to work out the preliminary details of the mathematical mechanism by which the ionization for high energies becomes suppressed. While the application of the theory is in a preliminary stage the thought is that it should contain within itself, when supplemented by a more complete knowledge of nuclear structure than we have at present, the story of the generation of these showers.

An extension of these principles enables us to realize another possibility in the matter of that problem of long standing, the explanation of the maintenance of the earth's charge. It will be recalled that the earth is charged to such an extent as to give a potential gradient of about 150 volts per meter at the surface. This charge is passing off on account of the conductivity of the atmosphere at a rate which would insure that 90 per cent. of it would disappear in 10 minutes were there no means of replenishing the loss. Many attempts have been made to account for the replenishment, but all are attended with serious difficulties. To provide for the replenishment through the agency of a charged particle current entering the earth, it would be necessary to assume the entrance of about 1,500 electrons per square centimeter per second. These would, in the light of our customary beliefs, produce enormously more ionization than is observed. If, however, we invoke the idea of absence of ionization for sufficiently high energies, it is possible to permit the entry of these charged particles into the earth. Of course, in their passage through the earth, their energy will eventually become reduced to the point at which they would produce ionization, so that at first sight we might suppose that the ionization, in a closed vessel, for example, would, after diminishing with descent into the earth, start to increase again at sufficiently low depths. Although the high energy rays might have a very long path, even a mile or so in the earth, the place where they produced ionization at the end of their range would be very

[21] "The Representation of Radiation Reaction in Wave Mechanics." *Phys. Rev.*, **44**, No. 11, 943–944, December 1, 1933; also, JOUR. OF FRANKLIN INST., **217**, No. 1, 59–71, January, 1934.

limited in extent. Once they started to produce ions, they would all be absorbed in a distance of perhaps fifty feet, so that the place of rapid increase of ionization might be very difficult to find. It is perhaps not without significance that in a recent letter from one of Professor Clay's collaborators I learned that, from some results as yet unpublished, Professor Clay has obtained a sudden drop to practically zero ionization below 270 meters of water and just above this a rise.

A further point of interest in relation to these matters concerns a calculation, the details of which I published last year.[22] This calculation is to the following effect. Suppose that we confine our attention to those showers in which at least one hundred particles are emitted within a semi cone angle of $\pi/4$ and assume for the primary rays producing them an absorption coefficient equal to that component of the cosmic radiation which Millikan has cited as responsible for 90 per cent. of the ionization in the atmosphere, the absorption coefficient which, moreover, Dr. Johnson has found as representing the rays responsible for the directional effect; and suppose further that we assume a rate of production of these showers at sea level such as is consistent with experimental findings. Then we find that as much as one-quarter of the total ionization at sea level can be accounted for by the shower particles of this type. It is therefore not unreasonable to suppose that when showers of all kinds are taken into account, practically the whole of the cosmic ray ionization of the atmosphere may be accounted for by them.

Origin of Charged Particle Energy.—The origin of charged particles of energies comparable with 10^{10} volts presents, of course, an interesting field for speculation. If they come from the stars, it is certain that positives and negatives must be emitted in equal numbers; for, if not, a star would soon become charged to an enormous potential which would prevent further departure. Thus, if the sun emitted from its surface no more electrons per square centimeter per second than fall per square centimeter per second on the surface of the earth as electron cosmic rays, it would charge at the rate of about 3×10^{10} volts per year. Since both signs must be emitted equally in the

[22] "Hoffmann Stösse and the Origin of Cosmic-Ray Ionization." *Phys. Rev.*, 44, No. 12, 1025–1027, December 15, 1933.

steady state, it is obvious that neither sign of charge can receive its energy from a potential field originating in the emitting body; for a field which would promote the departure of one sign would prevent the departure of the other.

A whole galaxy of stars with but small charge on each could, in the aggregate, secure for the galaxy a potential of large amount.[23] Consider a galaxy of radius R, containing N stars, each of radius a, and charged to a potential V in relation to a point sensibly infinitely distant from itself but yet falling within the galaxy. It can readily be shown that the potential at the surface of the galaxy is $W = VaN/R$. If n is the number of stars per unit volume, this amounts to $4\pi R^2 Van/3$. This increases rapidly with R for fixed values of V, a, and n, so that, for sufficiently large values of R, W may be made large compared with V and we may secure a high potential difference between the body of the galaxy and intergalactic space by the assumption of a relatively small value of V. Unfortunately, when applied to the actual condition in the known galaxies, the possibilities of size are not sufficiently great to enable us to secure values of W even as great as V.

Apart from this, however, in such a charged galactic system, charged particles could dive through the galaxy, but particles of both signs could not enter. Such a situation, however, would lead us into difficulties of another kind, for, as I have shown elsewhere,[24] if we had in the space between the stars a density of particles moving with the velocity of light and such as to correspond to a cosmic ray intensity equal to that observable upon the earth, they would, if of one sign, produce a space charge such as to give rise to differences of potential of the order of 10^{18} volts between points in space separated by no more than one light year. This latter conclusion constitutes a very potent argument in favor of the view that, if the cosmic ray intensity exists in charged particle form throughout space, the density of both signs of charge must be sensibly equal.

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[23] "Methods of Acquirement of Cosmic-Ray Energies." *Phys. Rev.*, **42**, No. 6, 914, December 15, 1932; also, "Cosmic Rays." *The Military Engineer*, **26**, No. 146, 116–120, March-April, 1934.

[24] "Space Density of Cosmic-Ray Particles." *Phys. Rev.*, **44**, No. 2, 124, July 15, 1933.

A possibility exists for the acquirement of high energies by charged particles without the invocation of large potential differences,[25] as I pointed out in my report last year. A change in magnetic field produces an electromotive force in any circuit through which the flux is changing. Now we know that sunspots are associated with magnetic fields and, therefore, it is easy to believe that such spots would exist on the stars. The magnetic field of a sunspot can grow to about 2000 gauss in about 10 days. Without invoking the stellar spots themselves as origin of cosmic ray energies, I wish merely to use them as evidence of the existence of changing magnetic fields upon these stellar bodies. The practical fact then is that if, over the region of a star, we have an area whose diameter is comparable with fifty times the diameter of the earth, and in which a magnetic field is growing at a rate comparable with that at which it grows in a sunspot, then through the processes of electromagnetic induction, an electron would acquire an energy of 10^{10} volts in one second, and before the field had grown to more than one-thousandth of a gauss.

I may cite another possibility of a more speculative nature but possessing nevertheless certain advantages.[26] Many years ago, in order to provide an explanation of the earth's charge, of its magnetic field and several other matters, I proposed a modified scheme of electrodynamics. One of the consequences of this scheme was the prediction of a slow death of the positive charge in the case of a rotating body so that the surplus negative gradually accumulated until it built up a field in the atmosphere which insured that it passed away from the earth's surface at a constant rate such as would maintain equilibrium. If now, on the basis of this hypothesis we continue to trace the passage of the electricity off into space we see a growing volume distribution of electricity thinning out in density as we go outwards but continually increasing in total amount. This growing volume of electricity produces a difference of potential between the sphere and a point infinitely distant from it. If we allow the process to go on for an

[25] "A Mechanism of Acquirement of Cosmic-Ray Energies by Electrons." *Phys. Rev.*, **43**, No. 4, 217–220, February 15, 1933.

[26] "Cosmical Electric Fields." *Phys. Rev.*, **45**, No. 4, 295, Feb. 15, 1934.

infinite time we find that the potential difference amounts to infinity, but the rate at which it mounts gets so slow as time goes on that even astronomical times are not sufficient to result in more than differences of potential which, though large, are of an order of magnitude significant in cosmic ray phenomena. Thus if we should consider a star as large as the sun, with a surface density of current equal to that for the earth, we should find that in seventy years the potential difference between the star and infinity would have grown to about 6×10^9 volts. In order for it to grow to six times this amount 70 million years would be necessary, so that, as I have remarked, even the invocation of astronomical time would not lead to potentials which were out of the realm of reason. As a matter of fact, the actual situation rising out of the physical mechanism which this example is designed to illustrate becomes complicated by various considerations involving the distances of the galactic systems from each other, the places of origin of cosmic rays, and so forth. All that I wish to emphasize is the possibilities inherent in a situation of this kind for the realization of potential differences of the order of magnitude comparable with those encountered in cosmic ray phenomena and such extrapolations into the regions of even higher energy as reason would permit.

PREPARATIONS FOR INVESTIGATIONS IN THE STRATOSPHERE,

Preparations are being made for certain investigations in the field of atmospheric electricity and cosmic rays, to be carried out in the forthcoming flights by Prof. Jean Piccard and Captain A. W. Stevens into the stratosphere.

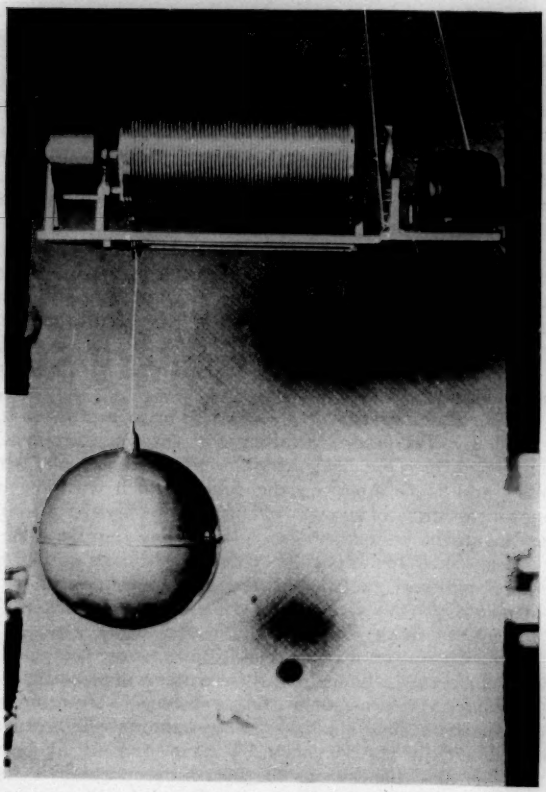
Measurement of Potential Gradient.—It is already known that the earth has an electric field which causes a change of potential of about 150 volts for each meter that we rise above the surface. This potential gradient, as it is called, diminishes with altitude until at an altitude of about 10 kilometers it has been found to be practically zero. Former measurements of this variation with altitude are limited in number and have been attended with difficulty on account of the charge which accumulates on the balloon and conspires to vitiate the results. It has been suggested that in the forthcoming flight of Captain Stevens, the opportunity should be taken to remeas-

ure the variation of potential gradient with altitude and particularly to see whether anything peculiar happens above those altitudes at which measurements so far have been made. For this reason I have devised a scheme which operates on principles quite different from those formerly employed in this kind of work. Fig. 34 is a picture of the apparatus. It comprises a drum with a screw thread on it. A large metal ball hanging on the end of a metal cable 100 ft. long can be wound up on this drum; and, in fact, by a suitable mechanism it can be made to travel up and down. The drum is insulated and the potential change in each ten centimeters of the ball's ascent or descent is recorded automatically by a procedure into whose details it is unnecessary for me to enter now. The important thing is that the device enables one to deduce the variation of potential along a vertical axis of the balloon to a distance comparable with its diameter, and so, by mathematical procedure, to dissect out from the resultant electric field at any point, that part which is produced by the charges on the balloon and the desired part which is the earth's potential gradient itself.

Cosmic Ray Experiments.—In addition to apparatus to be supplied by Professor Millikan for the measurement of ionization in closed vessels at different altitudes, Dr. Montgomery and I are adapting the sphere which we have been using for the study of showers of corpuscular rays to automatic recording in the balloon. Above the sphere there will be 600 lbs. of lead which forms part of Professor Millikan's apparatus. This lead will serve as the shower producing material in our experiments.

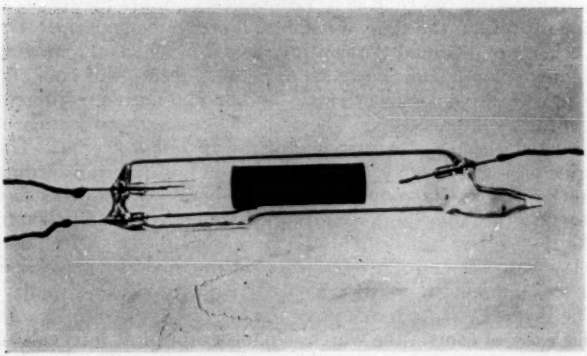
The use of Geiger counters in the stratosphere presents a problem with special features resulting from the fact that the density of the rays which affect the counter will probably be 60 or 100 times as great as at the earth's surface. After making a careful mathematical analysis of the elements which must be provided for in the situation, I have arrived at certain dimensions and dispositions of the counters which it seems should give the most satisfactory results under the conditions to be experienced, including the time available at the different altitudes. As the result of this we are building an apparatus which will record the intensity at four different angles from the

FIG. 34.



vertical and which will by rotation of the balloon give the intensities at different azimuths. As a result of the work of Drs. Locher, Johnson and Stevenson, we have acquired a large amount of information as to the best type of counters to use and the particular counter element to be employed is shown in Fig. 35. Following the practice adopted by Locher,

FIG. 35.



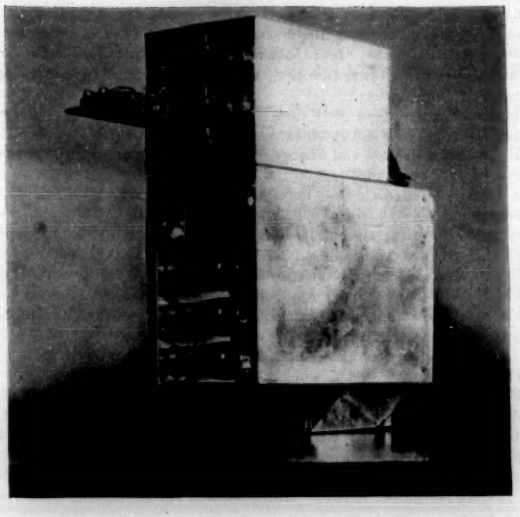
it is filled with argon at a pressure of 8 cms. of mercury. Three such elements form a unit and three such units form a telescopic assemblage. Two such telescopic assemblages used in parallel serve to increase the total counting rate. Then the whole apparatus is duplicated with an additional feature designed to take account of and eliminate the effect of those showers, to which I have already referred, in what would otherwise be their tendency to vitiate the observations given by the counter elements. In all, therefore, we have four counter telescopes, all of which contribute to the measurement of the intensity at any one angle, and there is a provision for the possibility that if either half goes wrong, the other half will continue to operate. Then the whole arrangement is duplicated so that in all there are four complete sets, one for each angle. The circuits associated with these counters are essentially of the type originally introduced by Rossi and

which have been used extensively in this laboratory by Drs. Johnson and Stevenson, by Dr. Locher, and by Dr. and Mrs. Montgomery and myself.

A vital element concerns the ultimate recording mechanism which must record very rapidly, for even with only one count per second for any one angle it is necessary that the ultimate recording mechanism shall resolve two counts which are no more than one-hundredth of a second apart if an error of no more than one per cent. is to be made by counts falling occasionally within the time of resolution of the mechanism. Dr. Locher has designed a recording device in which the moving elements are of sufficiently small mass to secure this end, and with which it is possible to make on one film fourteen different records simultaneously. The device has also the advantage of giving the times of occurrence of the recorded events. The principle of adapting a watch as the ultimate recording mechanism was introduced some time ago by Dr. Locher and recently this adaptation has been extended by Dr. Johnson to the removal of sufficient of the mechanism of the watch and relay associated with it to insure that the final moving part is of small enough mass to act with greatly increased rapidity. The readings of the watch are recorded photographically. In this case, of course, the watch is photographed at intervals so that one obtains the number of counts in an interval rather than the time of the individual counts. It is probable that we shall use both Dr. Locher's device and Dr. Johnson's for the recording mechanism as a check, and to provide for the possible failure of one or the other. Fig. 36 is a picture of the unit associated with the measurements of the cosmic ray intensity for a single angle. It comprises in all 48 different counter elements and the various circuits associated with them. These counter elements, as I have stated, exist in the form of four independent counter telescopes with six additional counters which are used for the purpose of elimination and measurement of showers.

Even with this lengthy survey it has been impossible to include an account of all of the investigations in progress. Thus I have omitted completely an investigation by Mr. Chambers on the effect of high fields in pulling electrons out of metals, an investigation by Dr. Hugh Darby concerned with

FIG. 36.



certain problems in bio-physics, and certain theoretical investigations by Dr. Cairns, Dr. Bramley and myself in the field of atomic structure. As an appendix to this report there is attached a list of the actual publications which have appeared in the period bounded by the date of this report and that of last year.

APPENDIX.

PUBLICATIONS OF THE BARTOL RESEARCH FOUNDATION

APRIL 19, 1933–APRIL 18, 1934.

The Masses of Atoms and the Structure of Atomic Nuclei—K. T. BAINBRIDGE JOUR. FRANK. INST., **215**, No. 5, 509–534, May, 1933.

Continuous Beta-Ray Spectrum—A. BRAMLEY. *Phys. Rev.*, **43**, No. 9, 767, May 1, 1933.

The Azimuthal Asymmetry of the Cosmic Radiation—T. H. JOHNSON. *Phys. Rev.*, **43**, No. 10, 834–835, May 15, 1933; JOUR. FRANK. INST., **215**, No. 6, 749–753, June, 1933. Also presented A.P.S., Washington, April 27–29, 1933.

On the Nature of the Primary Cosmic Radiation—W. F. G. SWANN. *Phys. Rev.*, **43**, No. 11, 945–946, June 1, 1933.

A System of Temperature Control—H. H. DARBY AND C. B. BRIDGES. JOUR. FRANK. INST., **215**, No. 6, 723–729, June, 1933.

Insects and Micro-Climates—H. H. DARBY. *Nature*, **131**, 639, June 10, 1933.

Cosmic-Ray Nuclear Disintegrations—W. F. G. SWANN AND C. G. MONTGOMERY. *Phys. Rev.*, **44**, No. 1, 52–53, July 1, 1933.

The Masses of the Lithium Isotopes—K. T. BAINBRIDGE. *Phys. Rev.*, **44**, No. 1, 56–57, July 1, 1933.

Comparison of the Masses of H^2 and Helium—K. T. BAINBRIDGE. *Phys. Rev.*, **44**, No. 1, 57, July 1, 1933.

The Equivalence of Mass and Energy—K. T. BAINBRIDGE. *Phys. Rev.*, **44**, No. 2, 123, July 15, 1933.

Space Density of Cosmic-Ray Particles—W. F. G. SWANN. *Phys. Rev.*, **44**, No. 2, 124, July 15, 1933.

The Asymmetry of the Cosmic Radiation at Swarthmore—T. H. JOHNSON AND E. C. STEVENSON. *Phys Rev.*, **44**, No. 2, 125–136, July 15, 1933.

Application of Liouville's Theorem to Electron Orbits in the Earth's Magnetic Field—W. F. G. SWANN. *Phys. Rev.*, **44**, No. 5, 224–227, August 1, 1933.

Band Spectra Measurement of Mass—A. BRAMLEY. *Phys. Rev.*, **44**, No. 4, 309–310, August 15, 1933.

The Cosmic Ray Hodoscope—T. H. JOHNSON AND E. C. STEVENSON. JOUR. FRANK. INST., **216**, No. 3, 329–337, September, 1933.

The Possibility of the Emission of Positive Electrons from the Nucleus by Rays—A. BRAMLEY. JOUR. FRANK. INST., **216**, No. 4, 427–428, October, 1933.

Distribution of Cosmic-Ray Nuclear Disintegration in Time—C. G. AND D. D. MONTGOMERY. *Phys. Rev.*, **44**, No. 9, 779, November 1, 1933.

Neutrons from Cosmic-Ray Stösse—G. L. LOCHER. *Phys. Rev.*, **44**, No. 9, 779–780, November 1, 1933. Also presented A.P.S., Boston, December 28–30, 1933.

The Amplification and Recording of Rapid Geiger-Müller Counter Impulses—G. L. LOCHER. JOUR. FRANK. INST., **216**, No. 5, 553–558, November, 1933.

The Distribution of Cosmic Ray Paths in a Vertical Cylinder—W. F. G. SWANN. JOUR. FRANK. INST., **216**, No. 5, 559–581, November, 1933.

The Distribution of Cosmic Ray Paths in a Vertical Cylinder—D. L. MACADAM AND M. R. LIPMAN. JOUR. FRANK. INST., **216**, No. 5, 583–589, November, 1933.

Azimuthal Asymmetry of the Cosmic Radiation in Colorado—E. C. STEVENSON. *Phys. Rev.*, **44**, No. 10, 855, November 15, 1933.

Preliminary Report of the Results of Angular Distribution Measurements of the Cosmic Radiation in Equatorial Latitudes—T. H. JOHNSON. *Phys. Rev.*, **44**, No. 10, 856–858, November 15, 1933.

Cloud Photographs of Cosmic Ray Stösse—G. L. LOCHER. JOUR. FRANK. INST., **216**, No. 6, 673–682, December, 1933.

Representation of Radiation Reaction in Wave Mechanics—W. F. G. SWANN. *Phys. Rev.*, **44**, No. 11, 943–944, December 1, 1933, JOUR. FRANK. INST., **217**, No. 1, 59–72, January, 1934.

Absorption Measurements of Cosmic Radiation—T. H. JOHNSON. *Rev. of Scientific Instruments*, **4**, 639–641, December 1, 1933; JOUR. FRANK. INST., **217**, No. 2, 167–172, February, 1934.

Measurement of Ionization per Centimeter of Path by Individual Cosmic Rays—W. F. G. SWANN. *Phys. Rev.*, **44**, No. 12, 961–968, December 15, 1933.

Hoffmann Stösse and the Origin of Cosmic Ray Ionization—W. F. G. SWANN. *Phys. Rev.*, **44**, No. 12, 1025–1027, December 15, 1933.

Experiments on the Distribution of Low-Energy Cosmic Rays in the Atmosphere—W. E. DANFORTH, JR. AND M. R. LIPMAN. JOUR. FRANK. INST., **217**, No. 1, 73–78, January, 1934.

Ionization by Cosmic-Ray Particles and Swift Beta-Particles—G. L. LOCHER. JOUR. FRANK. INST., **217**, No. 1, 39–58, January, 1934.

A Possible Explanation of Distribution in Size of Hoffmann Stösse—C. G. MONTGOMERY. *Phys. Rev.*, **45**, No. 1, 62–63, January 1, 1934. Also presented A.P.S., Boston, December 28–30, 1933.

The Mechanism of Asymmetry in the Alpheidæ—H. H. DARBY. Papers from Tortugas Laboratory, Vol. XXVIII. Carnegie Institution of Washington Publications, No. 435, 347–361, February, 1934.

Analysis of Cosmic Ray Deflection Experiments. Part I. The Magnetic Deflection Experiments of Curtiss and Mott-Smith—W. E. DANFORTH, JR. JOUR. FRANK. INST., **217**, No. 3, 331–345, March, 1934.

Cosmic Rays—W. F. G. SWANN. *Military Engineer*, Vol. XXVI, No. 146, 116–120, March–April, 1934.

Vacuum Tube Characteristics in Relation to the Selection of Coincident Pulses from Cosmic Ray Counters—L. R. FUSSELL, JR. AND T. H. JOHNSON. JOUR. FRANK. INST., **217**, No. 4, 517–524, April, 1934

The Architecture of the Universe—W. F. G. SWANN. Macmillan Co. New York.

PAPERS PRESENTED AT MEETINGS OF AMERICAN PHYSICAL SOCIETY BUT NOT PUBLISHED.

Washington Meeting, April 27–29, 1933.

The Isotopic Constitution of Krypton, Mercury, Selenium, Cadmium and Germanium—K. T. BAINBRIDGE.

Chicago Meeting, June 19–24, 1933.

The Masses of Isotopes and the Disintegrations of Atoms—K. T. BAINBRIDGE. (Invited paper.)

Boston Meeting, December 28–30, 1933.

Directional Measurements of the Cosmic Radiation and their Significance—T. H. JOHNSON.

Boston Meeting, December 28–30, 1933 (Cont.).

The Measurement of Absolute X-Ray Intensities and Absolute Sensitivity of X-Ray Film with a Geiger-Mueller Counter—G. L. LOCHER AND D. P. LEGALLEY.

Cosmical Electric Fields—W. F. G. SWANN.

Presented before the National Academy of Sciences, Washington, D. C., April 25, 1933.

Phenomena Associated with Cosmic Rays—W. F. G. SWANN.

Recent Dust Explosions.—Engineers in the Chemical Engineering Division of the Bureau of Chemistry and Soils report that precautionary measures recommended by the Department of Agriculture as the result of research on dust explosion prevention have proved effective in limiting the effects of recent explosions in grain handling operations. Thus in the explosion in the Missouri Pacific grain elevator at St. Louis on May 8, when seven workmen died from burns in the resulting fire, investigators are of the opinion that the loss of life would have been much greater if provisions for venting had been omitted when the elevator was constructed.

The Department engineers have investigated seven major dust explosions in industrial establishments in recent months. An explosion of barley malt dust in Buffalo, N. Y., in January caused the loss of two lives and injuries to fourteen firemen. An explosion of wood dust in a chair factory in Cleveland, Ohio, in March resulted in the death of two workmen and an explosion of white corn dust in the grain elevator of a large flour mill in Wichita Falls, Texas, caused the death of one employee, injuries to three others and extensive property damage. An explosion of wheat dust in a grain elevator at Amarillo, Texas, in April caused injuries to three men and complete destruction of the elevator and an explosion of feed dust in a mill in Riverdale, Illinois, in the same month caused extensive property damage. An explosion of aluminum powder in a factory in Painesville, Ohio, on May 19, resulted in the death of five men and extensive property damage. Including that of the St. Louis grain elevator, these seven explosions have caused the death of 16 persons, injuries to 36 others and property loss of more than one million dollars. C.

Air Conditioning Bibliography.—In response to the current popular demand for information covering air conditioning, humidification, de-humidification, insulation, refrigeration and ventilation, the Bureau of Foreign and Domestic Commerce has sponsored the preparation of a bibliography. In view of the extensive information published in recent years on the subject of air conditioning, this bibliography is by no means complete. With a few exceptions, material published prior to 1929 has been omitted entirely; for the years 1929–1932, inclusive, only a fragmentary list of references has been compiled; for 1933 and the early part of 1934 an effort has been made to present a more representative list of material published on the subject of air conditioning during the period.

C.

MEDAL DAY MEETING.

The annual Medal Day Meeting of The Franklin Institute was held in the Hall of the Institute at three-thirty o'clock on the afternoon of Wednesday, May sixteenth, 1934. This was the first Medal Day Meeting to be held in the Institute's new home—The Benjamin Franklin Memorial and The Franklin Institute on the Parkway in Philadelphia.

The meeting which was also the regular monthly meeting was called to order by the President, Mr. Nathan Hayward.

Upon motion, the minutes of the preceding monthly meeting were approved as printed in the JOURNAL OF THE FRANKLIN INSTITUTE. The presentation of the Certificates of Merit, Medals and Certificates of Honorary Membership were the next order of business. All awards recommended by the Committee on Science and the Arts during the current Institute year were made at this time.

AWARD OF CERTIFICATES OF MERIT

To Mr. Albert Allen, Winchester, Massachusetts. Mr. William G. Ellis, sponsor.

The President called upon Mr. Ellis.

Mr. Ellis: "Mr. President, I have the honor to present to you Mr. Albert Allen to receive a Certificate of Merit 'in consideration of the development of a system for continuously controlling the specific weight of sheet material in produc-into.'"

The President presented the Certificate as follows: "Mr. Allen, by power vested in me as President of The Franklin Institute, I have the honor to present to you a Certificate of Merit."

Mr. Allen expressed his thanks for this award.

To Mr. Joseph Grundy Shryock, Philadelphia, Pennsylvania. Mr. Henry H. Quimby, sponsor.

The President called upon Mr. Quimby.

Mr. Quimby: "Mr. President, I wish to present Mr. Joseph Grundy Shryock of Philadelphia, to receive a Certifi-

cate of Merit 'in consideration of the ingenious combination of standard, structural shapes in the formation of a light bridge-floor.'"

The President presented the Certificate as follows: "Mr. Shryock, upon the recommendation of the Committee on Science and the Arts, which has just been read, I present to you this Certificate of Merit with much pleasure."

Mr. Shyrock expressed his deep appreciation for the honor conferred upon him.

AWARD OF LONGSTRETH MEDAL

To Mr. William E. Sykes, Buffalo, New York, Mr. Coleman Sellers, 3rd, sponsor.

The President called upon Mr. Sellers.

Mr. Sellers: "Mr. President, upon recommendation of the Committee on Science and the Arts of The Franklin Institute, I present to you Mr. William Edwin Sykes of Buffalo, New York, to receive a Longstreth Medal 'in consideration of the design and development of the Sykes Gear Generators.'"

The President presented the Medal as follows: "In accordance with the citation just read, I am most happy to present to you, Mr. Sykes, an Edward Longstreth Medal."

Mr. Sykes uttered warm expressions of appreciation.

AWARD OF WETHERILL MEDALS

To Mr. Johann B. Ostermeier, Augsburg, Germany. Received by German Consul, Mr. Arno P. Mowitz. Mr. Walter H. Fulweiler, sponsor.

The President called upon Mr. Fulweiler.

Mr. Fulweiler: "Mr. President, upon recommendation of the Committee on Science and the Arts of The Franklin Institute, Mr. Johann B. Ostermeier of Augsburg, Germany, has been awarded the John Price Wetherill Medal 'in consideration of the very careful and scientific development of all of the factors involved in the production of a dust-free flash lamp, utilizing the combustion of aluminum foil in an atmosphere of oxygen in a closed glass bulb, whereby an intensely luminous flash of short duration is obtained in a safe and convenient manner.' Unfortunately, Mr. Ostermeier

had to change his plans at the last moment and was unable to come to America to receive the medal in person.

"In his absence I present the German Consul of Philadelphia, who will receive the medal on behalf of Mr. Ostermeier."

The President presented the Medal as follows: "Mr. Consul, we are honored by your presence here today, which is occasioned by the desire on our part to pay tribute to one of your distinguished countrymen.

"We recognize Mr. Ostermeier for his development of the photo-flash lamp. You, who, on account of your distinguished position, are frequently photographed by the newspapers, appreciate the importance of this lamp which has made it possible for your friends to recognize you when the picture is published.

"I hand you the Wetherill Medal and ask you to transmit it to Mr. Johann B. Ostermeier, the scholar whom you represent today."

The German Consul responded: "Mr. President, as a representative of the German Government, I am pleased to accept this honor on behalf of a distinguished native of Germany and to express to you the appreciation of Mr. Ostermeier and to assure you that the Government of which he is a part appreciates the honor which you extend to him today."

To Messrs: E. Newton Harvey, Princeton, New Jersey, and Alfred L. Loomis, Tuxedo Park, New York. Dr. George S. Crampton, sponsor.

The President called upon Dr. Crampton.

Dr. Crampton: "Mr. Chairman, the Board of Managers of The Franklin Institute has voted to award to Dr. E. Newton Harvey of Princeton, New Jersey, and Mr. Alfred L. Loomis of Tuxedo Park, New York, the John Price Wetherill Medal 'in consideration of the ingenuity and novelty of the Centrifuge-Microscope through which science is given a new tool of value and much promise.' While the award is a joint one, the Committee on Science and the Arts recommends that each gentleman be given a medal."

The President presented the medals as follows: "Gentlemen, on behalf of The Franklin Institute, it gives me keenest

pleasure to present these medals to you who have proved that, whether as a vocation or an avocation, science yields its secrets to those who are willing to serve."

Dr. Harvey and Mr. Loomis made known their grateful appreciation for the honor conferred.

AWARD OF THE LEVY MEDAL

To Dr. Kenneth T. Bainbridge, Cambridge, England. Received by Dr. W. F. G. Swann. Dr. Winthrop R. Wright, sponsor.

The President called upon Dr. Wright.

Dr. Wright: "Upon recommendation of the Committee on Science and the Arts, it is my privilege to present to you, in absentia, Dr. Kenneth T. Bainbridge of Cambridge, England, who has been voted the award of a Levy Medal for the paper on 'The Masses of Atoms and the Structure of Atomic Nuclei,' published in the Journal of the Institute for May, 1933.

"This medal is awarded each year for that paper which appears in the Journal of the Institute during the preceding calendar year and which is deemed by the Committee on Science and the Arts to present in excellent literary style the researches of the author which are of the greatest importance. The paper of Dr. Bainbridge was so judged by the Committee. In his absence the medal will be received by Dr. W. F. G. Swann, Director of the Bartol Research Laboratories of The Franklin Institute, of which Foundation Dr. Bainbridge was one of the foremost Fellows."

The President presented the medal as follows: "Dr. Swann, we all rejoice with you in the award of this high honor, given upon the recommendation of the Committee on Science and the Arts, to one of our outstanding Fellows.

"We ask you to receive this Medal in behalf of Dr. Kenneth T. Bainbridge, a Bartol Fellow, at the present time working with that extraordinary group of physicists in Cambridge, England. This Medal was won by Dr. Bainbridge through his own personal work and ability, but it carries with it great honor, not only to Dr. Bainbridge, but to you who have inspired and guided these young men in the Bartol Laboratory towards distinction and usefulness. Dr. Bain-

bridge in his letters expresses his grateful appreciation of your guidance in his work."

Dr. Swann said: "Mr. President. On behalf of Dr. Bainbridge I wish to express high appreciation of the honor The Franklin Institute has done him in awarding him this medal. The Bartol Foundation is a comparatively new atom in that little universe which constitutes the world's centers of investigation in Physical Science. It is naturally very proud of its isotope Dr. Bainbridge, whose activities have played so large a part in crystallizing its position among its fellow elements."

AWARD OF THE POTTS MEDAL

To Mr. Ernst Georg Fischer, Washington, D. C. Dr. T. D. Cope, sponsor.

The President called upon Dr. Cope.

Dr. Cope: "Mr. President, I am pleased to be permitted to present to you Mr. Ernst Georg Fischer of the U. S. Coast and Geodetic Survey, who has been awarded the Howard N. Potts Medal 'in recognition of a lifetime spent with marked success in the design of instruments of precision.'"

The President presented the medal as follows: "I have the honor as President of this old Society, which has always been in close touch with your Department in Washington, to hand to you this Potts Medal, in recognition of your work through long years spent in exceedingly useful scientific service of the Government."

Mr. Fischer was most grateful for this recognition of his lifetime work.

AWARD OF THE CRESSON MEDALS

To Mr. Stuart Ballantine, Boonton, New Jersey. Mr. W. C. Wagner, sponsor.

The President called upon Mr. Wagner.

Mr. Wagner: "Mr. President, as a member of the Sub-Committee of the Committee on Science and the Arts, which recommended the award, I am pleased to present to you Mr. Stuart Ballantine of Boonton, New Jersey. Your Committee is pleased to report that upon investigation they were unani-

mously of the opinion that this award should be made to Mr. Ballantine 'in consideration of his contributions to our knowledge of design principles for electromagnetic radiating structures resulting in greatly improved effectiveness for frequencies now being employed for radio broadcasting.'

"Mr. Ballantine has devoted many years of research to his particular field and has met with distinguished success in his work.

"I take much pleasure in presenting Mr. Ballantine."

The President presented the medal as follows: "Mr. Ballantine, upon recommendation of our Committee on Science and the Arts, it is my privilege to present to you the Elliott Cresson Gold Medal, for your brilliant work in the field of radio."

Mr. Ballantine expressed his thanks.

To the Union Switch and Signal Company, Swissvale, Pennsylvania. Represented by Mr. W. H. Cadwallader, Vice-President. Mr. James D. Lee, sponsor.

The President called upon Mr. Lee.

Mr. Lee: "Mr. President, it is my privilege to represent the Committee on Science and the Arts in presenting to you Mr. W. H. Cadwallader, Vice-President of the Union Switch and Signal Company, Swissvale, Pennsylvania, which company has been voted an Elliott Cresson Medal 'in consideration of the merits of the inventions embodied in the code system of the continuous automatic train stop and the automatic cab signal system which, in combination, serve to promote safety of railroad travel and at the same time to increase traffic capacity.'

"Mr. Cadwallader has been kind enough to come to Philadelphia on this occasion to represent his company, which company has made this outstanding contribution to safety of operation in railroading.

"I present Mr. Cadwallader on behalf of the Union Switch and Signal Company."

The President presented the medal as follows: "Mr. Cadwallader, I present to you the Cresson Medal which has been awarded to 'The Union Switch and Signal Company' for the development of 'Cab Signaling.'

"Your President has assigned to you the honor ot repre-

senting your Company. I congratulate you and through you your Company on this well-earned recognition."

In accepting the award Mr. Cadwallader said: "I just want to express my own appreciation and the appreciation and pleasure of the company which I represent for this honor which has been conferred upon us."

AWARD OF FRANKLIN MEDALS

To Henry Norris Russell, A.M., Ph.D., Sc.D., Princeton University, Princeton, New Jersey. Dr. H. Jermain Creighton, sponsor.

The President called upon Dr. Creighton.

Dr. Creighton: "Mr. President, I have the honor to present to you upon recommendation of the Committee on Science and the Arts, Dr. Henry Norris Russell as the recipient of a Franklin Medal 'in recognition of his diversified and brilliant contributions to scientific knowledge in the field of astronomy and astro-physics, particularly pioneer work in the application of physical theories to astronomical problems, and his researches on stellar constitution and evolution.'

"In connection with this award I would like to state briefly some personal and scientific facts regarding our honored guest:

"Dr. Russell was born at Oyster Bay, New York, in 1877. He received the degree of A.B. from Princeton University in his twentieth year, and that of Doctor of Philosophy in 1900 from the same institution. The years 1902 to 1905 he spent at Cambridge, England, first as a research student at King's College and later as a Carnegie research assistant at the observatory. He returned to Princeton University in 1905, where he has held the positions of instructor, assistant professor, professor and research professor in astronomy, and where he has taught such well-known astronomers as Shapley, Joy, and Menzel.

"Dr. Russell is a member of many scientific societies and a foreign associate of the Royal Astronomical Society. He is the Chairman of the committee on Stellar Spectra of the International Astronomical Union, and a member of its committees on double stars, stellar parallaxes, stellar statistics, solar spectroscopy, stellar constitution, and notation and

units. In 1931 he served as the President of the American Philosophical Society, and at the last meeting of the American Association for the Advancement of Science he was elected its President for the ensuing year. Harvard University, Dartmouth and Louvain have honoured him with their degrees. In 1921 he was awarded the Gold Medal of the Royal Astronomical Society; in 1922 the Lalande Medal by the French Academy, and the Draper Medal by the National Academy; in 1925 the Bruce Medal by the Pacific Astronomical Society, and in the same year the Rumford Medal by the American Academy of Arts and Science.

"Doctor Russell first attained general recognition about 1913, as the result of his notable work in the field of stellar constitution and evolution. His luminosity-diagram, showing the relation between the intrinsic brightnesses of stars and their surface temperatures, and leading to the recognition of main sequence stars, giants and dwarfs, has exercised a controlling influence on stellar research for two decades. In the field of spectroscopic analysis and its astro-physical applications his investigations have been of very great scientific value. Doctor Russell's study of the spectroscopic binaries and their orbits has contributed largely to our knowledge of the mass and density of these systems. His work on solar and stellar atmospheres, including the abundance of the various chemical elements, conditions of temperature and pressure, and the nature of the physical conditions in these atmospheres is of the highest rank, and has yielded results which are accepted as representing the best determinations available on these fundamental data. His computation of the dynamic parallaxes of double stars constitutes a significant contribution. Indeed, there is hardly a field in astro-physics that has not been influenced by his work."

The President then presented the Medal, the Certificate and the Certificate of Honorary Membership, as follows: "By authority vested in me as President of The Franklin Institute, I have the honor to present to you the Franklin Medal, the highest honor which it is the privilege of the Institute to award and with this Medal I hand you a Certificate of Honorary Membership in The Franklin Institute.

"In presenting this Medal to you, Sir, we honor a great scholar from a great university."

Dr. Russell made proper acknowledgement of the honor conferred upon him.

To Irving Langmuir, A.M., Ph.D., Sc.D., D.Ing., LL.D., General Electric Company, Schenectady, New York. Dr. H. Jermain Creighton, sponsor.

The President called upon Dr. Creighton.

Dr. Creighton: "Mr. President, The Board of Managers of The Franklin Institute, upon the recommendation of its Committee on Science and the Arts, is unanimously of the opinion that a Franklin Medal be awarded to Dr. Irving Langmuir 'in recognition of his numerous and fundamental researches in chemistry and physics, especially his work in the domain of surface chemistry, and of the many benefits bestowed on modern civilization through the results of his investigations.'

"Dr. Langmuir was born at Brooklyn, New York, in 1881. He received the degree of Metallurgical Engineer from Columbia University in 1903, and that of Doctor of Philosophy from Göttingen, Germany, in 1906. On returning to the United States he was appointed an instructor in chemistry at the Stevens Institute of Technology. In 1909 he joined the research staff of the General Electric Company, and in 1932 he was made an Associate Director of the Research Laboratory of this organization.

"Doctor Langmuir is a member of many learned societies, including the American Chemical Society of which he was President in 1929. He is also an honorary member of five European scientific societies, a distinction shared by but few Americans. He is the recipient of many other honors. Honorary degrees have been conferred on him by Northwestern University, Princeton University, Union College, Yale University, the University of Edinburgh and the Technische Hochschule, Berlin-Charlottenburg. In 1918 he was awarded the Hughes Medal by the Royal Society; in 1921 the Rumford Medal by the American Academy of Arts and Science; in 1925 the Cannizzaro Prize by the National Academy of Rome; in 1928 the Perkin Medal by the Society of Chemical Industry; in 1928 the School of Mines Medal by Columbia University, and the Chandler Medal; in 1930 the Willard Gibbs Medal; and in 1932 the Nobel Prize. He has the unique distinction of having twice been awarded the Nichols Medal.

"Doctor Langmuir's investigations cover a vast range in both chemistry and physics. His early work was largely devoted to the study of chemical reactions and physical processes at low pressures, and electron emission and space charge. This led to the development of the vacuum tube industry and to important advances in the electric lamp industry, thereby bringing about marked improvements in electric lighting and radio communication. His work on the orientation of molecules in films of molecular thickness has contributed to our knowledge of the surface structure and energy of liquids; and his determination of the heat of dissociation of hydrogen molecules led to the development of the atomic hydrogen torch. Doctor Langmuir's extension of Professor G. N. Lewis' work on atomic structure, between 1917 and 1920, resulted in a new and broad conception of chemical valence. This theory, signally confirmed by the developments of wave mechanics, has enabled the chemist better to understand the mechanism of compound formation. The study of adsorption phenomena, and of the evaporation of molecules from, and their condensation on solid surfaces, led Langmuir to formulate an entirely new and essentially chemical theory of the mechanism of adsorption and catalytic effects, in which the adsorbed molecules occupy definite positions on the adsorbing surface. In some cases the surface is almost entirely covered and in others it is relatively bare. This theory is of both theoretical and practical importance in the field of heterogeneous catalysis. At present, Doctor Langmuir is engaged in working out the laws according to which atoms and molecules distribute themselves over the surfaces of liquids and solids forming unimolecular layers."

The President then presented the Medal, the Certificate and the Certificate of Honorary Membership, as follows: "As President of The Franklin Institute, I have the honor to present to you, Sir, the Franklin Medal and a Certificate of Honorary Membership in The Franklin Institute. Your work in the field of physics and chemistry, which has been so well described, calls for this recognition, which is the highest in our power to award.

"It adds to the pleasure of The Franklin Institute, in making this award, to recognize a man of that group of

Scientists who have been so close to the Institute over so many years."

Dr. Langmuir stated: "It gives me great pleasure to accept this award from The Franklin Institute. I also deeply appreciate the document which goes with it."

In introducing the speakers Mr. Hayward said: "We never give a Franklin Medal without expecting the recipient to work for it. We will now ask them to get to work.

"I have the pleasure and honor of introducing Dr. Henry Norris Russell, who will give us the pleasure of reading a paper."

Dr. Russell: "Before I work for my medal let me do something which is not work but a great pleasure. Let me express to you, Mr. President, and to the Committee on Science and the Arts and the Institute as a whole, my deep indebtedness for this distinguished honor which you have seen fit to confer upon me. I know what it means. In that respect I can say no more but I would say that it is an added pleasure to me to receive this medal in the presence of an old friend and former colleague of nearly forty years standing—The Secretary of The Franklin Institute, and also in the presence of another friend of many years, my very distinguished colleague, Dr. Langmuir.

"Now I am not sure before I go on whether I am going to work on something you like. A medalist usually talks a few minutes upon some subject upon which he has been working. I have decided to talk on 'The Atmospheres of the Stars.' * I shall not read my paper for a person who reads his paper does not deserve a medal."

Mr. Hayward: "Dr. Langmuir, we shall now ask you to read your paper." †

After an expression of appreciation to all those who had participated in these exercises, the President declared the meeting adjourned.

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* See page 127, this issue.

† See page 143, this issue.

Dust Travels East.—The heavy dust storms that originated on the Great Plains the early part of May, this year, have been the subject of much comment and undoubtedly will give the U. S. Department of Agriculture considerable concern for several years to come. All these vast expanses of alluvial soil were once covered with a closely woven mattress of grassy vegetation. The annihilation of the protective cloak of nature came as an inevitable result of attempts to place the land under cultivation or intensive grazing. With the soil exposed and returned to its original powdery state by a prolonged dry spell, a dense mass of air rushing down from the Canadian plains with increasing momentum transformed the land into whirling dust clouds which travelled east with gradual expanding force.

According to the U. S. D. A. Clip Sheet No. 831, the dust cloud of this year was the heaviest ever experienced by the city of Washington, D. C. Measurements by the United States Weather Bureau showed that each cubic inch of air over the Capital contained 150,000 particles of dust. The normal dust count is 6,400. The particles were almost twice the size of those usually present and it is estimated that 5,000 tons of western real estate were constantly floating over the city during the day.

But apparently the dust was not 100 per cent. mineral matter as one might connote from the term "soil." In *Science* for July 6, M. H. SOULE of the Hygienic Laboratory, University of Michigan, announces that the dust-storm brought to his laboratory a liberal supply of organisms. It happened that on the day of the storm, 120 students opened an average of 5 nutrient medium plates for intervals of less than 2 minutes each. Next day practically every agar surface contained 3 to 5 glistening, raised, brownish mucoid colonies. The species was identified as *B. megatherium*, a common non-pathogenic spore-forming aerobic bacillus. The germ was not common to this particular laboratory and unquestionably was storm-borne.

C.

PRINCIPLES OF STATISTICAL ANALYSIS OCCASIONALLY OVERLOOKED.

BY

A. G. MCNISH.

CRITICISM BY

AXEL CORLIN,

Observatory of Lund.

Under the above title A. G. McNish in the JOURNAL OF THE FRANKLIN INSTITUTE, Vol. 215, page 697, No. 6, June 1933, has enumerated seven principles "of statistical theory," which, according to his opinion, have been overlooked by several investigators, especially those working in the cosmic ray field. Some of these principles (1, 4) are rather self-evident and have not been seriously overlooked by anybody of the investigators cited by McNish, when they have drawn any pronounced conclusion from their data. Whether the "statistical individual" is one "complete diurnal-variation series" or is one hour-value depends evidently upon the problem to be treated; mathematical statistics do not *a priori* dictate any special time-interval as more proper than others, and the suitable time-interval and the domains of error and correctness are regulated by inherent properties of the material.

In (3) McNish states that successive records of the cosmic rays are associated in magnitude with those preceding and following every value and that they are not independent of each other. He further writes: "If the apparatus were adapted for 5-minute registration-intervals instead of 1-hour intervals, the divisors * would have been $\sqrt{12 \times N}$, thus reducing the dispersion to about one-third of its previously given value, and, *ad absurdum*, if the time-interval had been infinitely short so that an infinite number of observations could have been made, the solar diurnal-variation could have been deduced with *absolute certainty* from a single day's

* The square root of the number of observations to divide the dispersion with, in order to get the mean error of the mean value.

observation alone."—It is inconceivable that a scientist takes the opportunity to criticise the wholly correct method of other investigators, when he seems to have so little knowledge about matter in question as this statement shows. When the time-interval is taken only one-twelfth of the previous time-interval, the now calculated mean error of the mean value is *not at all* one-third of "its previously given value" or is being changed successively in one direction, when the time-interval is taken successively less. McNish seems to be ignorant of the rather fundamental fact that also the numerator (here the dispersion, or the mean error of a single value) is correspondingly altered. The sum of the squares of the residuals, the dispersion, and the mean error of the mean value must evidently be calculated for *the same time-interval*, and both the numerator and the denominator are altered, when another time-interval is selected. In the paper by F. V. Hess and the author, cited by McNish, this interval was the whole period in question, and the dispersion was not calculated for one hour and the mean error of the mean value for the whole period (or for any other time-interval than the dispersion), which would be an erroneous method.

In (3) McNish tries to prove that the cosmic ray records are not independent of each other by quoting some figures from a paper by E. Steinke with reference to *Zs. Phys.*, **45**, 595–596 (1927). At the cited place, however, there is no paper by E. Steinke but a paper by K. Büttner, where no such figures are to be found. McNish had probably in mind a paper by E. Steinke in *Zs. Phys.*, **42**, and pages 582–583 (1927) so that the year should be correct. McNish now states that "the dispersion of single values throughout a day is on the average $\pm$ 10 mV. If the values were independent, the dispersion of the daily means would be $(10/\sqrt{17})mV$ or $\pm$ 2.4 mV for days on which 17 observations were made. However, it is found that the dispersion of the daily means is $\pm$ 5 mV, demonstrating the interdependence of successive values."—But unfortunately $\pm$ 10 mV is *not* "the dispersion of single values" but the mean error of the mean values as was also expressly mentioned by Steinke, and the dispersion of single values is on the average $\pm$ 29 mV. Accordingly, if we, like McNish, divide by $\sqrt{17}$, we obtain $\pm$ 7.1 mV instead

of $\pm$ 2.4 mV, which, according to the method by McNish to show the independence or interdependence, shows just the opposite to what McNish wishes to show! It is true that the cosmic ray records sometimes are high, sometimes are low throughout (sometimes) several days according to the so called "variations of the second kind," which may be some form of interdependence between successive values for irregular time-intervals, and accordingly the calculated dispersion for long periods is a maximum value, which we just wish to have in order to prevent false conclusions about small variations. But which principle has induced McNish to draw the limit between independence and interdependence between the diurnal series?

In (6) McNish calculates correctly the mean error of the differences between two extreme points on a curve by E. Steinke, which was in fact overlooked by Steinke, but McNish makes a mistake in thinking that it is the probable error. This mistake wholly misleads him in (7), where his theoretically calculated "occurrences of differences A" are valid for multiples of the probable error, having one limit of practical certainty, but the observed number of differences are valid for multiples of the mean error, having another limit of practical certainty. His comparison is therefore erroneous, and, in fact, several of Steinke differences are more than four times the correct mean error ($\pm$ 2.5 mV) of the differences, which is sufficient to consider at least some of them real. with a high degree of probability.

REPLY TO DR. CORLIN'S REMARKS BY DR. MCNISH.

There is nothing in the original paper which I should care to modify. Dr. Corlin is quite correct in his statement that the statistical "individual" is uniquely determined by the problem involved, as was implied in my paper. If the problem investigated is diurnal variation, then one day's variation constitutes an individual. Likewise, when the problem is to ascertain if the day-time value exceeds the night-time value, the individual is the difference between one day and one corresponding night, regardless of how many observations may be involved in each.

Dr. Corlin states in his second paragraph that the writer seemed ignorant of the fact that the reduction of the time-interval would tend to increase the numerator as well as the denominator. It was purposely stated, with this in view, that the dispersion would be reduced "to about one-third." Had the numerator remained constant, the reduction would have been to $1/\sqrt{12}$. From acquaintance with cosmic-ray observations the allowance made for the variation of the numerator appears to be approximately correct. The illustration of an infinite number of time-intervals is still cogent for, while the denominator increases without limit, the numerator remains finite so that their quotient approaches zero.

In the third paragraph Dr. Corlin errs in assuming that I had in mind a certain paper to which reference was not made. He failed to read the proper footnote which correctly gives the reference (page 699 of the article). My statements in this connection are quite sound and in accord with the reference cited.

In his fourth and last paragraph Dr. Corlin says that I made a mistake in thinking that I was dealing with the probable error. It is to be noted, however, that the value taken is definitely called the "wahrscheinlicher Fehler" by the author in the place cited.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

RADIO ECHOES.

Special signals are being transmitted from two European radio stations for the study of long-delay echoes. The signals and the whole undertaking are adapted to the participation of persons all over the world who have high-frequency receiving sets, no technical training being required. Long-delay echoes are a most surprising and baffling phenomenon. Mr. J. Hals was listening in Norway, one day in 1927, to telegraphic signals from station PCJJ in Holland on a frequency of about 9,600 kc/s. Some of the signals were followed, after about 3 seconds, by a faint echo or reproduction. Echo signals occurring one-seventh of a second after an emitted signal had been well known, being due to the reception of waves that had travelled all the way around the earth. But the discovery of echoes after a materially greater interval than a seventh of a second immediately raised the puzzling question of where such an echo could come from.

The phenomenon has been verified in a few scattered observations by Dutch, British, and French engineers. Echoes have been heard from 1 to 30 seconds after the emitted signal. Not enough is known, however, to determine what causes the echo signals nor how they are propagated. Two theories have been proposed. One, by Dr. C. Stormer of Norway, is based on the assumption that there are streams of electrons in space some hundreds of thousands of miles out from the earth's equator, converging in a vast toroid upon the magnetic poles of the earth, and accounting for the aurora borealis or northern lights. Doctor Stormer supposes that the signals are reflected from these electron streams in space. According to the other theory, advanced by Dr. B. Van der Pol and Prof. E. V. Appleton, these echoes are due to a slowing up and reflection of the waves by a peculiar distribution of ionization in the very high levels of the ionosphere (that portion of the atmosphere

* Communicated by the Director.

65 miles and more above the surface of the earth which is responsible for all long-distance radio transmission).

The British Broadcasting Corporation through its magazine, *World-Radio*, and with the aid of Professor Appleton, has just inaugurated a worldwide endeavor to learn more about these long-delay echoes. Special emissions are provided from two high-power, high-frequency stations to facilitate observations by anyone who cares to listen with a high-frequency receiving set. Listeners in all parts of the world have been enrolled in the endeavor, over 10,000 of them in Great Britain. It seems likely that information of unique value to science will result, and an orderly explanation of the curious phenomenon developed, when definite data are secured on the frequencies and the times of day and season at which these echoes occur, their intensities, the area over which a given echo is heard, their relation to magnetic storms, sunspots, etc.

The stations transmitting the special signals are GSB, Daventry, England, and HBL, Geneva, Switzerland (The League of Nations station). The GSB signals are transmitted on 9,510 kc/s, with a tone or modulation of 1,000 cycles per second, each Sunday, Tuesday, and Thursday, from 3:25 to 3:55 A.M., Eastern Standard Time. The HBL signals are transmitted on 6,675 kc/s, unmodulated continuous waves, each Sunday, Wednesday, and Friday, from 6:00 to 6:30 A.M., Eastern Standard Time. Each transmission consists of a five-minute adjusting period (GSB using phonographic music, and HBL using its call letters in morse code repeated) followed by the letters of the alphabet in morse code, spaced a minute apart. Thus, for instance, GSB transmits the letter A in morse code at 3:30, and after a minute of silence the letter B at 3:31, then the letter C at 3:32, etc., finishing with the letter Z at 3:55. During the one-minute intervals between signals the observers listen for echoes and observe the elapsed time in seconds with a watch having a seconds hand. It should be noted that the GSB signals are receivable with a receiving set as used for broadcast programs but the HBL signals are unmodulated CW and therefore require an oscillating receiving set.

Dr. J. H. Dellinger, chief of the radio section of the National Bureau of Standards, would be very glad to have any

successful reception of long-delay echoes in the United States reported to him, and will relay the information to the British authorities who are coördinating the investigation for the world as a whole. Observers should give the identifying letter of the signal observed, the time to the nearest second at which the direct signal was heard, the time to the nearest second at which the echo was heard, an estimate of the relative intensities of direct signal and echo, a description of the sharpness or apparent shape of the echo, and any pertinent information on interference, fading of signals, or other conditions of the observations.

Doctor Dellinger would be interested also in receiving reports on reception of long-delay echoes on any other stations, especially high-frequency stations in the United States. It may, on the other hand, be difficult to be certain of any echoes observed because of the lack of silent periods as in the special signals from the two European stations.

Summaries of the results of this investigation will be made available later in publications in this country. Persons desiring to keep in touch with all details of the project meanwhile can do so by consulting the weekly issues of *World-Radio*, published by Broadcasting House, London, W. 1, England.

STRESSES IN ENAMELS.

It was announced in Technical News Bulletin no. 195 (July 1933), that a study of the stresses set up in enamel coatings during cooling, after firing on a metal base, was being undertaken. The expansivity of commercial enamels is higher above their critical temperatures, and lower below their critical temperatures, than enameling iron. Hence upon cooling after firing the tendency is first to set up a tensile stress in the enamel as it cools toward its critical temperature, and then to relieve this stress and set up a compressive one on further cooling. The data indicated that the initial tensile stress never grows very large, because it is relieved by yielding of the enamel. It was possible to relieve virtually all of this tensile stress by a carefully controlled cooling schedule. No further yielding appeared to occur below the critical temperature, and the stresses below this temperature depend upon the net differential contraction of the iron and enamel. Tests

have shown that this net differential contraction, and the corresponding stress, can be changed by retarding the rate of cooling of the enamel behind that of the iron, and vice versa. For a given ground coat enamel, normally in compression at room temperature, the stress is increased by an increase in the time or temperature of firing.

TESTS OF RED LEAD PAINTS.

Five and one-half years ago a large number of steel panels painted with two coats of red lead paints were exposed on the roof of the chemistry building at 45 degrees facing south. The formulas consisted of 20, 22, 25, 28, 30, 33, 35 and 40 pounds of red lead (95 per cent. grade) to one gallon of boiled linseed oil (no thinner or drier added). Thus far the paints have failed exactly in order of increasing amount of red lead, the first one to fail being the paint composed of 20 pounds of red lead to one gallon of oil. At this time ($5\frac{1}{2}$ years exposure), the paint composed of 28 pounds of red lead to one gallon of oil has failed (rusting). The 30, 33, 35 and 40 pound paints are still in good condition.

PROPERTIES OF SATURATED STEAM.

The remarkable development of the steam engine, which reached its height in the early part of the present century, owed much to the so-called "steam tables" or tables setting forth the properties of steam at various temperatures and pressures. These tables were based largely upon the experimental work of Regnault, which was carried out about 80 years ago. There were hardly any serious attempts to improve upon Regnault's work for some 50 or 60 years, but with the development of the steam turbine, higher temperatures and pressures were introduced, and the existing data were no longer adequate, either as to accuracy or range of temperature and pressure.

In the early 1900's, a considerable amount of work on the properties of steam was done in Germany and England, and a little elsewhere, but it was not until 1921 that a few members of the American Society of Mechanical Engineers, realizing that practice had gone far beyond research, initiated a movement to conduct a series of systematic investigations of the properties of saturated and superheated steam.

The experimental work was assigned to Harvard University, under the direction of Dr. H. N. Davis; to Massachusetts Institute of Technology, under the direction of Dr. F. G. Keyes; and to the National Bureau of Standards, under the direction of Dr. N. S. Osborne. Later, arrangements were made to coördinate the work with that going on in European laboratories, and as a result two international steam conferences have been held, one in London in 1929, a second in Berlin in 1931, and arrangements are being made to hold the third in Boston, New York, and Washington during September of this year.

In the division of the work among the American laboratories, the part assigned to the Bureau was chiefly the calorimetric measurements, and was to cover both saturated and superheated steam. Work was begun actively some ten years ago, and the work on saturated steam is just being brought to a successful conclusion. Two calorimeters, one for the lower range of temperatures and pressures, the second for the higher range, were designed, constructed, and used in an extensive series of measurements, which extended from 0 to 373° C. (32 to 704° F.) and up to a pressure of 3,200 lb./in.^{2} In other words, the measurements extend to the limit of the range in which saturated steam can exist. In the course of the work it was found expedient to make other measurements, which, combined with the calorimetric data, will make it possible for the Bureau to present, at the forthcoming international conference, data on all the properties of water and saturated steam, needed for the preparation of a complete table.

The work has been generously supported by the steam using industries, and a large part of the cost has been met by them. The funds were handled and the work supervised by the special research committee on thermal properties of steam, organized by the American Society of Mechanical Engineers.

With the completion of the work on saturated steam, the staff is well prepared and much of the required equipment is available, to undertake the difficult task of investigating the properties of superheated steam. It is not yet clear just how the necessary funds for this work can be obtained, but with the very successful outcome of the first part of the work, it is

hoped that means will be found for its continuance, in order that knowledge of the properties of superheated steam may become as complete and accurate as our present knowledge of saturated steam.

RUBBER CEMENT FOR MOLD SURFACES.

During the month two large bronze plaques to be used at the entrance to the Bureau's grounds were cast in the experimental foundry. These plaques carry the Department of Commerce seal and the inscription, "National Bureau of Standards," in raised letters on a matte background. With regular foundry technique the results were not entirely satisfactory because of slight washing of the sand and other causes. The difficulty was overcome by spraying the mold surfaces with rubber cement, which caused the fine surface particles to adhere together firmly and assured the accurate reproduction of the details of the plaque. Also, this procedure permitted the casting of the metal in a green-sand mold. Economy in handling of the molds as well as in producing castings of a very excellent quality is obtained by the use of rubber cement surfacing. The use of rubber cement as a binder for foundry cores is described in the Bureau's letter circular no. 252 which may be obtained without charge upon application to the Bureau.

CORROSION OF FERROUS METALS IN ACID SOILS.

Local areas of corrosive soils containing accumulations of salts or other corrosive materials have been successfully located by appropriate methods, but little progress has been made in identifying corrosive areas in which salts or other soluble materials are present in very small concentrations, if at all. A characteristic feature of the soils of the eastern half of the United States as a class is their low concentration of soluble material. In order to identify corrosive soils low in soluble material and to account for their corrosiveness, it is necessary, therefore, to employ methods based on some characteristic of the soil other than its salt content.

Since the removal of the soluble material in soils by rainfall is generally accompanied by the development of an acid reaction in the soil, it was reasonable to assume that the

acidity of soils might be an important factor in their corrosiveness. The fact that a large number of the soils in which the Bureau's test sites are located show various degrees of acidity made it possible to investigate the importance of this factor in soil corrosion.

By comparing the average rates of pitting of ferrous specimens which have been buried for 8 and 10 years with values for the total acidity of the soils at the test sites, it was found that a definite relation exists between acidity and pitting. A similar relation was also obtained between the losses of weight of specimens in a short time laboratory test and the total acidity of the soils.

The effect of soil acidity in inducing corrosiveness was attributed to its action in preventing the formation of protective layers of ferrous and ferric hydroxides on the metal surface. In neutral and slightly alkaline soils the hydroxide film tends to reduce the accessibility of oxygen at the cathode surface, thereby reducing the rate of corrosion.

The effect on corrosion of the physical characteristics of soils which determine their permeability to air was studied by comparing data that measured permeability with an expression for the ratio of uncorroded to corroded area. The correlations obtained indicate that, assuming other factors to remain the same, the greater the permeability of the soils (exclusive of sands), the greater is the tendency for pitting.

For a more complete account of this work the July number of the *Journal of Research* (RP696) should be consulted.

Of Interest to Bookbinders.—R. W. FREY AND C. W. BEEBE of the Bureau of Chemistry and Soils have developed a heated gas chamber whereby leather may be "aged" in three to six months, instead of waiting for many years. As a result the comparative permanence of various kinds of leather can be studied more advantageously and through research develop for tanners and users more durable leathers.

Results on these rapid aging tests agree with previous research findings that sulphur acids from the air are one of the principal causes of deterioration, reddening, and breakdown of leather. These effects have been observed for years in libraries in which the leather bindings of books were injured. The cause was at first believed to be limited to the sulphur fumes resulting from burning of gas for lighting libraries. However, deterioration continued when electricity was substituted for gas and research has shown that in most cities the burning of coal for power and heat causes enough sulphur fumes in the air to rot leathers, particularly those vegetable tanned.

The aging operation consisted of placing leather samples in a cylinder in which a gas flame was kept burning continuously. The heat from the flame further intensified the effects of the fumes so that in six months some of the leathers were virtually destroyed. Other leathers retained most of their original strength and wearing qualities. Goatskin leather was notably more durable than cowhide or sheepskin leathers. Chrome tanned leathers were uniformly much more durable than vegetable tanned leathers. Generally the deterioration corresponded closely to the quantity of sulphur the leather had taken up from the atmosphere.

Although for certain purposes, bookbinding particularly, chrome leather has several undesirable characteristics, its resistance to acid rot is so much superior to vegetable leathers that it would be worth the while of leather chemists to eliminate certain undesired properties of chrome leathers for special purposes. Combinations of vegetable and chrome tanning are being studied in attempts to produce a resistant leather having both the preferred physical properties of a vegetable leather and the more rot resisting qualities of a chrome leather. Other treatments are being investigated, some of which from preliminary findings offer promise of doubling the life of many light leathers for bookbinding and upholstering.

C.

THE FRANKLIN INSTITUTE.

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NECROLOGY.

Dr. Henry Arnstein, Philadelphia.
Mr. W. H. Bassett, Cheshire, Conn.
Dr. Walton Clark, Chestnut Hill, Pa.

LIBRARY NOTES.

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BOOK REVIEWS.

ACHEMA JAHRBUCH JAHRGANG 1931–1934, BERICHTE ÜBER STAND UND ENTWICKLUNG DES CHEMISCHEN APPARATEWESENS, HERAUSGEGEBEN UNTER MITWIRKUNG VON FACHGENOSSEN AUS WISSENSCHAFT UND TECHNIK VON DER DECHEMA. 235 pages, illustrations, 15 × 21 cms. Ausstellungs-Führer ein Bezugsquellennachweis Chem. Apparate und Maschinen für Wissenschaft u. Technik, 119 pages, illustrations, 15 × 21 cms. Hannover, Deutsche Gesellschaft für Chemisches Apparatewesen, 1934.

The Achema Jahrbuch is a report upon the status and development of chemical apparatus and is published with the coöperation of scientists and technologists holding membership in the Dechema: The German Society for Chemical Apparatus.

The Achema is essentially a huge exhibition of machinery and apparatus used in the chemical industry. These exhibitions are held every other year or so, the one in 1934 being the seventh. Since the previous Achema held in 1931, much progress has been made in matters relating to chemical apparatus and the object of the Jahrbuch is to outline briefly and interestingly the many improvements the three past years have fostered. The reader of the Jahrbuch will have

an excellent idea concerning what is to be or, at this moment of writing, what has been displayed at the Achema.

All in all, the Jahrbuch is an extremely interesting document. It starts out with an introductory section on topics of general interest, such as the relation between the German Chemical Society and the Achema, a short note on Cologne, the 1934 exhibition city; an address of welcome to visiting chemists; short biographical sketches of famous German chemists; comments of domestic and foreign publications upon the 1930 Achema and finally, a short preview of the 1934 exhibition itself.

The second section is given over to purely scientific matters. The principal paper describes the development of chemical apparatus and the driving forces behind this development. Other articles deal with the advances in standardization of chemical apparatus; welded structures; new and simple instruments for measuring therapeutically active ultraviolet radiation from artificial and natural light sources; and, the "Drawinol" process for making absolute alcohol.

The third section embraces the technical and industrial features. First come the materials of construction and brief descriptions are furnished for pure platinum and new noble-metal alloys; corrosion resisting steels and alloys; acid-resistant alloys; nickel and its alloys; castings of chrome steel; new quartz glasses; acid resistant glass linings; the latest in chemical stoneware. These are followed by many other interesting articles describing the latest improvements in apparatus both for production and control.

The Jahrbuch ends with a list of the exhibitors followed by an alphabetically arranged list of the exhibits and the sponsors.

While on this topic, we must not fail to mention the Achema VII Exhibition Guide. This guide now supplants the Jahrbuch which was exhausted long before the exhibition opened. It is, at present, the only German, most complete and up-to-date directory of sources for the purchase of instruments and appliances for the laboratory as well as machinery, apparatus and auxiliaries for almost every special branch of the chemical industries. The price is RM 1.

T. K. CLEVELAND.

LES COLLOIDES, MANUEL DE CHIMIE COLLOIDALE. By H.-R. Kruyt, Professor of Physical Chemistry at the University of Utrecht. Translated from the English edition by J. Du Plessis De Grenedan, 329 pages, 16 × 23 cms., with 118 figures. Librairie Felix Alcan, Paris, 1933.

This is a monograph the worth of which is attested by the fact that the present French edition has come from the English translation by van Klooster of the original Dutch in its second edition (1929). Naturally in English speaking countries the van Klooster translation is to be preferred but it may be said that the French edition is easy to read and should not prove a stumbling block.

Few textbooks in English cover an equivalent field. The contents fall into four divisions, the first being a general introduction to the colloidal state, the second and third parts taking up in detail suspensoids and emulsoids respectively while the fourth part deals with certain special cases briefly. The treatment of the subject is strictly from the theoretical point of view and will help only those interested in colloidal problems from this angle. The author holds steadfastly to the purpose of developing the science of the colloidal state. This, still young,

is in course of rapid evolution and as the author freely admits it is inevitable that a textbook of such purpose and scope should reflect his personal points of view. There are few, however, who have a record of original contributions either longer or more varied and Professor Kruyt is qualified therefore to write with as broad a background as may be found.

It is to be hoped that subsequent editions will appear to keep step with progress in this field. The edition at hand appears to be comprehensive up to its date of publication (1929) such subjects as coacervation and thixotropy finding their proper place. All the older references through which the science of the colloidal state has been developed are there also, making Kruyt a name to be recommended to all students of the subject.

LESLIE R. BACON.

PHOTOMÉTRIE DES LUMIÈRES BRÈVES OU VARIABLES, par Madame Marguerite Moreau-Hanot, Docteur es sciences. Preface de M. Charles Fabry, Membre de l'Institut. 134 pages, figures, 16 × 25 cms., cloth. Encyclopédie Photométrique, Revue d'Optique, Paris, 1934. Price 25 francs.

Photometric determinations are commonly applied to radiations which have attained a fixed value, the "end conditions" or variations during minute periods of initial accretion and final diminution being negligible in comparison with the period of the observation under the stable fixed value. Modern applications of light radiations cannot be investigated in such a simple manner for it is often the variant value of the light-flux during a minute interval of time which must be determined. It is with these rapidly variable values of radiation, the methods of their determination and their application with which the author deals.

The subject is treated on a comprehensive plan beginning with the consideration of these visual phenomena: luminous sensation and duration of excitation, threshold of perception and brief illuminations, and persistence of visual perceptions. Proceeding to non-physiological methods we enter the realm of sensitometry, initiated by the classic researches of Hurter and Driffield, in the photographic examination of variable illuminations; and the production of brief illuminations and the measurement of their duration. Finally, photoelectric cells and their application to television and sound films are discussed.

Copious references to original papers, which the author has consulted, are included, and readers in the field of the physics of brief illuminations and their applications are fortunate in having in this compact form a logical digest of this now increasingly important literature.

L. E. P.

ELEMENTS OF POWER GENERATION, by Arthur M. Greene, Jr., Dean, School of Engineering, Princeton University; Sometime Professor of Mechanical Engineering, Rensselaer Polytechnic Institute; Junior Dean, School of Engineering, University of Missouri; Instructor, University of Pennsylvania. 314 pages, illustrations, 15 × 23 cms., cloth. New York, John Wiley & Sons, Inc., 1933. Price $3.25.

Power generation is a fundamental industry into which enter a copious variety of representative problems in dynamic engineering, and it has become common practice in engineering schools to dwell upon the devices of that industry as typical

applications of the principles which are employed in the profession of mechanical engineering. Students undertake the serious project of a course of study for this profession with a widely variant degree of general information on power-generating machinery. It is accordingly essential to provide for them a descriptive text on power installations and their component apparatus in order to insure that no vital topic may have escaped their notice in this initial step in their course of study.

The present work has been written with this object in view and provides a generously illustrated compendium of facts, figures and pictures of present-day power generating stations and their equipment. The illustrations, it may be mentioned, represent a superior quality of draftsmanship and photoengraving. Hydraulic and internal-combustion power plants are not overlooked but the work dwells mainly upon steam-driven stations and apparatus. Every topic is meticulously described, often with explanatory sidelights and numerical data for clarification, which appreciably lessen the task of the reader.

One of the author's objects is to provide precise terminology. That object is attained by emphasizing all names of parts described by the use of bold-faced type so that the name is emphatically associated with a picture or verbal description; a most desirable plan in a student's initial study. The subject-matter is arranged in logical order:—power generation and sources of power, combustion of fuels, boilers, boiler details and accessories, boiler-house appliances, power from steam or gas, machine details, valves, valve-gears and governors.

The work has a wider sphere of interest than as a descriptive text only for class-room use. It will appeal as well to such readers as may desire a compact reference work of modern power-plant apparatus. Nothing seems to have been omitted to provide the reader with a complete explanation of the equipment and operation of modern power installations.

L. E. P.

THE DESIGN AND USE OF INSTRUMENTS AND ACCURATE MECHANISM, UNDERLYING PRINCIPLES, by T. N. Whitehead, 283 pages, illustrations, plates, 15 × 22 cms. New York, The Macmillan Company, 1934.

"This book is written primarily for designers of instruments and for those who use them." However, the author further points out that the principles involved are subject to a wider application—to mechanism as a whole. Thus, clockmakers' precision lathes; carburetors and magnetos of internal combustion engines; the design of governors; many components of textile machinery; automatic and hand controls of all sorts; subsidiary parts of printing presses; all these involve degrees of precision, the development and maintenance of which depend upon close adherence to the methods set forth by the author.

Up to the present, the only coherent theory of error, as applied to the functioning of mechanisms, was the "theory of probability." Such theory is derived mathematically and, as the author points out, has only a limited utility. Drawing from experience as a designer and user of instruments, he presents a comprehensive analysis of the actual physical causes of inaccuracy and their relation to the design and construction of precision apparatus.

At the beginning, the author lists the three classifications of errors encountered in making measurements and shows the cause for such defects. Thus, there are (1) systematic errors, which are due generally to imperfection in "element"

design or construction. Such errors are constant and inherent to a particular instrument. Then there is (2) the short period error, produced by chance disturbances of the element through external causes. Vibration is a common example. The third type, the erratic error, is caused by incomplete relations between parts of an element, such as backlash between the gears composing a train. Erratic errors, although not unlike short period errors, are not so readily amenable to a mathematically derived relationship.

Part I of the book discusses the three types of faulty elements and their resultant errors. The matter of systematic errors is dealt with thoroughly in Chapter II. Such instruments as the Photomeasuring Micrometer, the Wimperis Accelerometer, and the Assay Balance, are mathematically examined for source and extent of errors caused by defects in design or faulty reproduction of design. In the discussion of Short Period Errors, the author demonstrates that a series of observations or readings will not necessarily follow the "Law of Errors" although the exercising of certain precautions will often render such a law operative. A great number of the erratic errors are caused by friction, something which tends to undergo constant change and can only be eliminated or satisfactorily controlled through machine design. Erratic errors, like short period errors, are inconstant, but they do not fluctuate about a settled mean, nor are they a function of a disturbance at any given instant, nor do they vanish when the disturbance ceases. In summarizing Part I, the author points out that the most hopeless error to meet in precise measurement is the erratic error, yet such errors are easiest to eliminate by design.

A study of the mental restoring agencies has disclosed a number of interesting facts. It was found that in setting a "graticule" upon a collimated line, each observer showed an individual "mean" setting. On repeating the set after a time interval, the mean usually changed, but the precision of the set remained about as before. The test of an experienced observer is to give him a good lunch or nap and see whether he will repeat his former settings. Very often he will not.

Part II should be of especial interest to instrument makers. The author shows how a maximum in precision may be attained through kinematic design. In this regard he distinguishes between those designs supplying the necessary restraint and those having the fault of over or redundant restraint. Numerous line drawings are supplied to make certain points clearer. Since many precision instruments must be of relatively robust construction, the point contacts of a kinematic design must give way to surface contacts in many places and so enters semikinematic design. If short period errors are to be held to a minimum, the matter of stiffness, isolation and protection of the elements must be considered. Examples are given on how to calculate the deflection of a pedestalled instrument due to wind pressure as well as its period and damping of vibration. A chapter on the necessary and minimum conditions for accuracy is particularly timely. The author makes the somewhat startling but apparently accurate statement that no possible error of any sort can arise by sighting on a goniometer with an axis determined by ball bearings, provided that readings on the circle are taken at both ends of a diameter. A second example of unnecessary steps to provide accuracy also is given. A chapter on "The Planning of an Instrument" is lengthy, but extremely worth while. Many types of design are critically described and the good or bad features of a number of popular precision instruments are frankly discussed.

Last but not least is a consideration of the Human Factor. An observer exercises both judgment and physical action when manipulating an instrument. Human judgment is influenced by irrelevant as well as relevant sensations, and it is the task of the instrument maker to keep all irrelevant factors at a minimum if reasonable accuracy is to be expected. A list of possible psychologically disturbing factors is given. The matter of physical action also receives respectful attention. The most accurate adjustments are made by the smoothest working controls. Smooth action also prevents muscular fatigue and its attendant psychological repercussions.

T. K. CLEVELAND.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 478, Experimental Verification of the Theory of Wind Tunnel Boundary Interference, by Theodore Theodorsen and Abe Silverstein. 17 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price ten cents.

The results of an experimental investigation on the boundary-correction factor, conducted at the N. A. C. A. laboratories at Langley Field, Va., are presented in this report. The values of the boundary-correction factor from the theory, which at the present time is virtually completed, are given in the paper for all conventional types of tunnels.

With the isolation of certain disturbing effects, the experimental boundary-correction factor was found to be in satisfactory agreement with the theoretically predicted values, thus verifying the soundness and sufficiency of the theoretical analysis. The establishment of a considerable velocity distortion, in the nature of a unique blocking effect, constitutes a principal result of the investigation.

The major portion of the investigation was carried on in the N. A. C. A. full-scale wind tunnel, which afforded the unusual opportunity of a direct comparison with flight results as a final verification.

Report No. 480, The Aerodynamic Effects of Wing Cut-Outs, by Albert Sherman, 8 pages, illustrations, 23 × 29 cms. Washington, Superintendent of Documents, 1934. Price five cents.

In connection with the interference program being conducted in the N. A. C. A. variable-density wind tunnel, an analysis was made of available material with the object of presenting a qualitative discussion of wing characteristics as affected by cut-outs and of determining means for their quantitative calculation.

The analysis indicated that extending a cut-out in the chord direction has much greater effect than extending it in the span direction. Unfairness in profile over the leading edge of the cut-out sections adversely affects the lift and induced drag as well as the profile drag.

Lifting-line airfoil theory can be successfully used to calculate the characteristics of a wing as affected by a cut-out when the section characteristics of the profiles along the span are known. It is useful, in such a problem, to employ the method of successive approximation for obtaining the span load distribution.

The information derived from the analysis was applied for illustration to the prediction of the characteristics of a wing with a center-section cut-out. The

values thus obtained were found to agree fairly well with the test results of a model of the cut-out wing measured in the variable-density wind tunnel.

INDUSTRIAL RADIOGRAPHY, by Ancel St. John, Ph.D., and Herbert R. Isenburger, 232 pages, illustrations, 15 × 24 cms. New York, John Wiley & Sons, Inc., London, Chapman & Hall, Ltd., 1934. Price $3.50.

This book should be of great interest to all workers in metallurgy. Makers of forgings, castings, welded structures and apparatus, drawings, rollings and the like are steadily increasing their resort to the x-ray for detecting internal defects in fabricated metal objects. The authors have set out to prepare a work of intense practical value. As such, most of the theoretical matter is omitted. Just sufficient subatomic physics have been added to nicely round out the subject. The use of a not-too scientific language places the work within the reach of the layman and at no time detracts from its real practical value to the engineer, metallurgist, plant manager or student.

While the authors have omitted no necessary detail relating to the practice of industrial radiography, the book proper reads like a novel in many of its sections. What reader is not interested in hearing how Roentgen discovered the matter-penetrating power of the x-ray; how large paintings are exographed (x-rayed) in establishing their authenticity; how x-ray operators guard against doses of over 13 roentgens per month; why a golf ball slices—or hooks!; why steel balls are buried in tooth paste, then exographed; and finally why, when the metal becomes too thick, recourse is had to the gamma-rays of radium which have about twice the energy of the best practical x-ray tube made today.

Not the least important parts of the book are the tables and charts included in the form of an appendix. These tables serve as adjuncts to Chapter XIX on operating and cast data. Using the tables, a manufacturer should be able to determine readily just what type of radiographic equipment is needed in his plant, the purchase price, operating costs for the five years and thereafter, as also the costs for inspecting welded longitudinal and girth seams and pressure vessels as a whole. It is interesting to see how rapidly costs mount as the thickness of metal exceeds three inches.

Apparently the authors are thoroughly experienced in the art of industrial radiography. They have taken considerable care to emphasize the importance of protection to the x-ray operators and describe in detail such precautions that must be taken. The chapter on Fluoroscopy will be found distinctly helpful. Special attention has been given to the interpretation of radiographs and the radiographing of complicated pieces of apparatus. The article on gamma-ray radiography is critical in scope and includes helpful cost data. The volume ends with an excellent bibliography of papers covering the industrial applications of x-rays. There are 426 references in all.

T. K. CLEVELAND.

PUBLICATIONS RECEIVED.

The Kinetic Theory of Gases, by Leonard B. Loeb, 2nd edition, 687 pages, illustrations, 15 × 23.5 cms. New York and London, McGraw-Hill Book Company, Inc., 1934. Price $6.00.

Theorie der Elektrizität, von R. Becker, Band I, 265 pages, illustrations, 15.5 × 23 cms. Leipzig und Berlin, B. G. Teubner, 1933. Price 14.50 marks.

Ocular Dioptrics and Lenses, by G. F. Alexander, 216 pages, illustrations, 16 × 23 cms. Baltimore, William Wood and Company, 1934. Price $4.75.

Electromagnetism, by Hector Munro MacDonald, 178 pages, 14.5 × 22.5 cms. London, G. Bell and Sons, Ltd., 1934. Price 12s. 6d.

Applied Acoustics, by Harry F. Olson and Frank Massa, 430 pages, illustrations, 15 × 22 cms. Philadelphia, P. Blakiston's Son & Co., Inc., Price $4.50.

Before the Dawn, by John Taine, 247 pages, 14 × 21 cms. Baltimore, The Williams and Wilkins Company, 1934. Price $2.00.

Berichte der Versuchsgrubengesellschaft, Heft 5, Dynamische Beanspruchungen von Forderseilen, von Dipl.-Ing. H. Herbst, unter Mitarbeit von Dipl.-Ing. W. Berke und Dipl.-Ing. H. Schussler, 140 pages, illustrations, 16 × 24 cms. Gelsenkirchen, Carl Bertenburg, 1934.

Canada Department of Mines, Limestones of Canada, Their Occurrence and Characteristics, Part II, Maritime Provinces, by M. F. Goudge, 186 pages, illustrations, tables, 16.5 × 25 cms. Ottawa, King's Printer, 1934. Price 50 cents. Investigations of Fuels and Fuel Testing, 1932, 155 pages, tables, plates, 16.5 × 25 cms. Ottawa, King's Printer, 1934.

The Cracking Art in 1933, by Gustav Egloff and Badona L. Levinson, 184 pages, 15 × 23 cms. Chicago, Universal Oil Products Co., 1934.

Frequency Measurements at Radio Frequencies, A Manual of Measurement and Monitoring Technique, 80 pages, illustrations, 17 × 25.5 cms. Cambridge, General Radio Company, 1933.

Bell Telephone Laboratories, Monograph B-786, Measurement of Wetting of Dielectrics, by D. A. McLean and G. T. Kohman, 9 pages, tables, 15 × 23 cms. B-787, Iron Shielding for Telephone Cables, by H. R. Moore, 16 pages, illustrations, 15 × 23 cms. B-789, Some New Theorems on Limits of Variation, by R. L. Peek, Jr., 7 pages, illustrations, 15 × 23 cms. New York, Bell Telephone Laboratories, 1934.

CURRENT TOPICS

Another Reducing Diet.—W. G. CAMPBELL, Chief of the Food and Drug Administration, reports the examination of a reducing "food" which consisted essentially of sugar, soya bean flour, cocoa and table salt. So great is its value in the opinion of the sponsor, it is marked to retail at two dollars for a seven-ounce package. Needless to say, the Administration did not permit the merchandizer to get away with it.

While on the subject a word might be said about dinitrophenol and related compounds. Taken internally, these compounds play the role of dangerous drugs. Clinical evidence shows that they act by increasing the metabolic rate. This amounts to a speeding up of the body processes, resulting in a destruction of the tissues, including fat, to provide fuel for the accelerated metabolism. Common symptoms are increased temperature, pulse or respiration, or copious sweating. In particular, Mr. Campbell warns, these drugs should not be used by individuals suffering from chronic rheumatism, alcoholism, tuberculosis or diseases of the heart, liver or kidneys, as poisonous and otherwise harmful effects are even more likely to manifest themselves.

It is inevitable that reducing agents containing these drugs have sprung up like mushrooms all over the country, and are endangering the lives of patrons. Although serving a useful purpose when the dosage is properly adapted to the needs of the individual patient, the proper dosage and indications for use, as well as prompt discovery of toxic effects, can be determined only by a skilled physician.

C.

Manufacturing Wind.—The National Advisory Committee for Aeronautics announces the allotment of sufficient funds to construct a full-speed (500 miles per hour) wind tunnel. Although the Committee's researches indicate that airplane speeds upward of 500 miles per hour are attainable, knowledge is yet lacking as to natural laws governing air flow above 200 miles per hour, and consequently higher attainable speeds cannot be used with safety.

This wind tunnel will be constructed at the laboratory of the National Advisory Committee for Aeronautics at Langley Field, Virginia. It will be built of reinforced concrete with steel plates lining the walls. The dimensions will be 154 by 51 by 25 feet high.

There will be an air flow of 500 miles per hour through a test chamber 8 feet in diameter. Eight thousand horse power will be required to attain this wind speed.

C.

Fouadin for Heart Worms in Dogs.—Dog owners and veterinarians now have available an effective means of combating dog heart worm, a parasite that has spread rapidly in recent years from the South to the Atlantic Coast States. DRS. WRIGHT and UNDERWOOD of the Bureau of Animal Industry, in coöperation with the Sportsmen's Gun-Dog Club of Philadelphia, have established that Fouadin, a complex antimony compound, will kill the worms and the larvæ.

Chemically, Fouadin is sodium-antimony-III-bis-pyrocatechindisulphonate of sodium. A suitable course of treatment with this drug, the investigators announce, will usually destroy some or all of the adult worms in the heart and pulmonary artery, and will free the blood stream of larvæ, thus preventing the infested dog from acting further as a spreader of the parasite to other dogs.

C.

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